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Modeling Water Quality and the Effects of Agricultural Best Management Practices in Four Mile Creek, Iowa

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This report describes an initial attempt to combine the detailed simulation of agricultural runoff and soil processes, which calculates surface and subsurface pollutant transport to receiving waters, with subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of watershed hydrology and water quality. Comparison of water quality conditions under conventional agronomic practices and BMPs provides the basis for determining the net effects and associated benefits of BMP implementation. Using simulated concentrations of pesticides and other toxic pollutants in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions can be determined to assess the aquatic impact of proposed practices.

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals.

The Hydrologic Simulation Program--FORTRAN (HSPF), developed through Athens Laboratory research, is a comprehensive technique for modeling water quality constituents in runoff from various land uses. To test the model's capabilities in evaluating the effects of agricultural best management practices (BMPs) on water quality, HSPF was applied to two watersheds in Iowa. The test demonstrated that HSPF is a flexible and realistic technique for BMP assessment in small watersheds and large river basins. Coupled with risk assessment procedures, the model can provide data for use in evaluating impacts of pollutants on selected aquatic organisms.

William T. Donaldson
Acting Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. However, runoff models by themselves are not sufficient to predict water quality effects of BMPs since instream transport and transformations are not usually represented. Although agricultural runoff models can be used to evaluate BMP effects on runoff and pollutant loadings from small, field-size areas, they must be linked with receiving water quality models to assess the quality in receiving waters resulting from BMPs applied to the watershed.

This report describes an initial attempt to combine the detailed simulation of agricultural runoff and soil processes, which calculates surface and subsurface pollutant transport to receiving waters, with subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of watershed hydrology and water quality. Comparison of water quality conditions under conventional agronomic practices and BMPs provides the basis for determining the net effects and associated benefits of BMP implementation. Using simulated concentrations of pesticides and other toxic pollutants in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions can be determined to assess the aquatic impact of proposed practices.

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Dr. James Baker and his staff at Iowa State University were instrumental in providing and interpreting the Four Mile Creek data used in this project. Dr. Baker was also a key source of information on soil nutrient and pesticide processes; the assistance and contributions of Dr. Baker and his staff are sincerely appreciated.

Among the authors, Mr. Anthony Donigian was Principal Investigator and Project Manager with overall responsibility for the technical direction and supervision of the project. Mr. John Imhoff was the Task Leader directing the incorporation of the CMRA methodology into HSPF and also assisting in the instream sediment and pesticide simulation. Mr. Brian Bicknell was the key staff engineer on the project performing code modifications and testing, preparing HSPF input sequences, executing simulation runs, and assisting in calibration and verification. Mr. Bicknell also performed the text editing and processing for the report.

Dr. Robert Johanson, professor at the University of the Pacific, Stockton, California developed the initial design for incorporation of the SERATRA model capabilities into HSPF, as consultant to Anderson-Nichols.

Many other individuals at Anderson-Nichols were active on this work. Mr. Jack Kittle was the Task Leader on the interface of the SERATRA and HSPF models, and he was our key technical source on all HSPF operational questions. Mr. Douglas Beyerlein directed the data base preparation and the initial hydrologic calibration. Ms. Mary Maffei provided clerical support and report typing throughout the project, and Ms. Virginia Rombach prepared the report charts and figures. The dedication and efforts of these individuals contributed greatly to the success of the project.

SECTION 1

INTRODUCTION

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. However, runoff models by themselves are not sufficient to predict water quality effects of BMPs since instream transport and transformations are not usually represented. Although agricultural runoff models can be used to evaluate BMP effects on runoff and pollutant loadings from small, field-size areas, they must be linked with receiving water quality models to assess the quality in receiving waters resulting from BMPs applied to the watershed. Moreover, the runoff and receiving water quality models must be compatibly designed, so that the runoff and agricultural pollutant loadings (e.g., sediment, pesticides, nutrients) can be accepted, transported, and transformed by the associated aquatic processes in the receiving water model. Thus, predicting water quality in agricultural watersheds requires integrated, comprehensive modeling systems so that conventional practices and changes affected by BMPs can be represented by the runoff models with the resulting water quality conditions determined by the receiving models.

It was recognized early in our work that a major problem in modeling watershed water quality would be the representation of sediment and pollutant delivery from generation on field-size areas to a stream, where the aquatic impact is exerted. Although sediment delivery (with associated pollutants) is entirely a land surface process, delivery and movement of soluble pollutants occurs by both surface and subsurface pathways; usually the subsurface path is dominant. The ability of integrated runoff/receiving water models to represent the delivery process is uncertain. Also, the manner in which BMPs affect the distribution between surface and subsurface pollutant transport and delivery has a significant impact on the resulting water quality. Thus, both of these problem areas are important to BMP analyses.

This paper describes the first significant attempt that we are aware of to combine the detailed simulation of agricultural runoff and soil processes, which calculates surface and subsurface pollutant transport to receiving waters, with subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of watershed hydrology and water quality. Comparison of water quality conditions under conventional agronomic practices and BMPs provides the basis for determining the net effects and associated benefits of BMP implementation. Using simulated concentrations of pesticides and other toxic pollutants in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions can be determined to assess the aquatic impact of proposed practices.

1.1 Iowa Field Evaluation Program Overview

The research and results presented in this report were performed as part of a comprehensive Field Evaluation Program (FEP) (U.S. EPA, 1979), sponsored by EPA and coordinated by the Athens Environmental Research Laboratory. The primary purposes of the FEP were to test and demonstrate (1) the capability of agricultural best management practices to achieve water quality goals, and (2) the applicability of two water quality planning tools - HSPF and the Chemical Migration and Risk Assessment (CMRA) methodology (Onishi et al., 1979) to the BMP evaluation and selection process.

These objectives of the FEP were largely accomplished through a series of studies in the Iowa-Cedar river basin in the State of Iowa (Figure 1.1). The primary focus of the FEP was the Four Mile Creek basin near Traer, Iowa, a 52 square kilometer agricultural watershed that has been the site of a study of sediment, nutrient, and pesticide fate and transport by EPA and Iowa State University.

Extensive field monitoring and data collection programs at the Four Mile Creek site supported the FEP to provide the necessary data for the BMP analysis and modeling efforts. HSPF and CMRA were then applied to the 7700 square kilometer Iowa River Basin above Coralville Reservoir to demonstrate the planning methodologies on a large river basin. The study included the participation of local farmers in Four Mile Creek site and local, state, and federal agencies in order to demonstrate the BMP evaluation, selection, and implementation process.

1.2 Modeling Analyses in the IFEP

Both HSPF and the CMRA methodology were applied in the Iowa FEP to evaluate and demonstrate their utility for BMP analyses. HSPF is a comprehensive program for modeling runoff, sediment, pesticides, nutrients, and other water quality constituents from urban, agriculture, and other land uses. It allows detailed simulation of stream hydraulics, water quality processes, pesticide and nutrient behavior in soil, lake reservoir dynamics, and sediment-contaminant transport. It also includes extensive

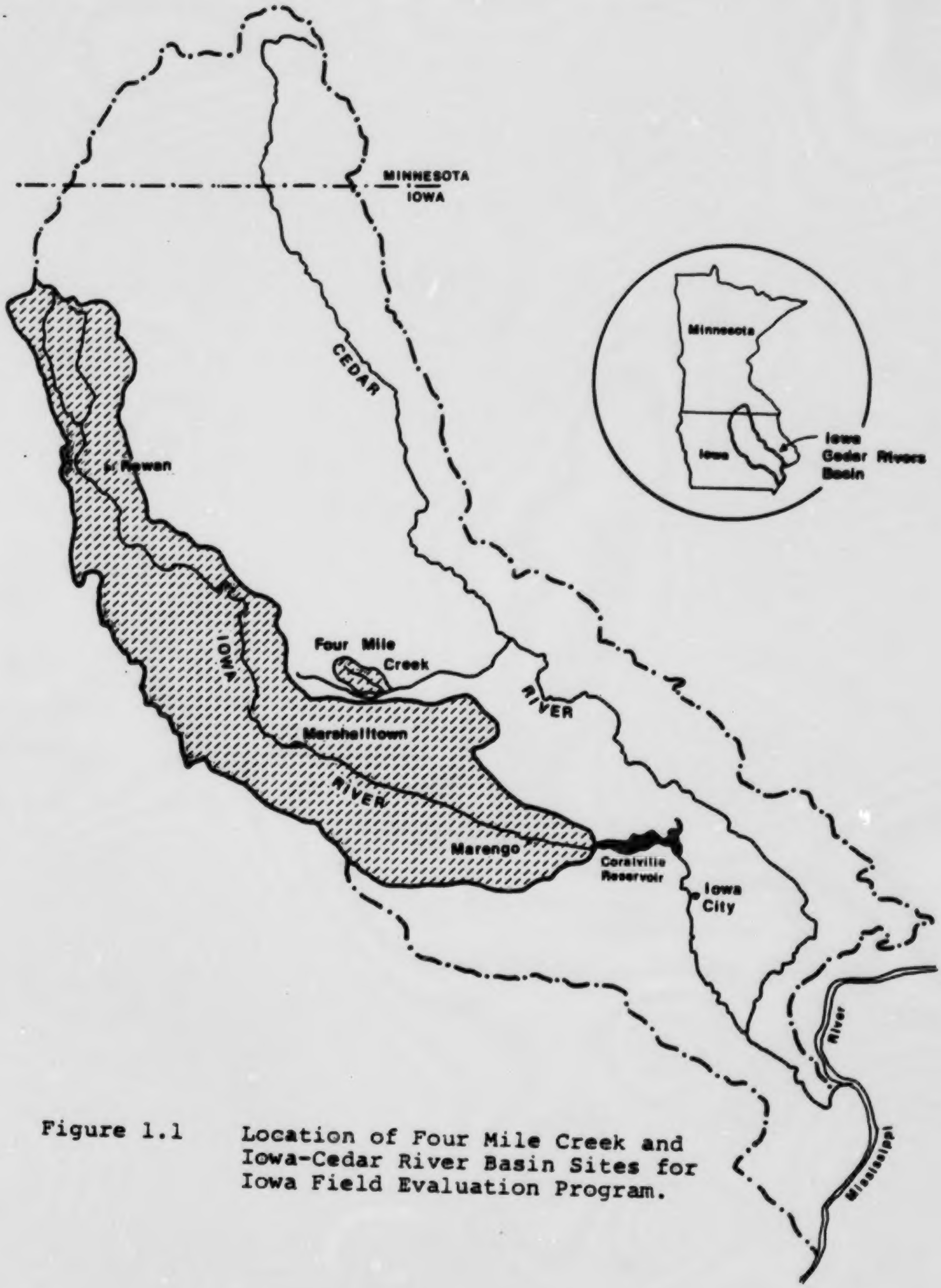

MINNESOTA
IOWA
CEDAR
RIVER
Rowan
IOWA
RIVER
Four Mile
Creek
Marshalltown
Marengo
Coralville
Reservoir
Iowa
City
River
Mississippi
Minnesota
Iowa
Iowa
Cedar Rivers
Basin

Figure 1.1 Location of Four Mile Creek and Iowa-Cedar River Basin Sites for Iowa Field Evaluation Program.

data handling and analysis procedures that support and complement the simulation capabilities.

The CMRA methodology provides procedures for detailed instream simulation of sediment and chemical transport and interactions to develop time series of chemical concentrations in streams. The time series is then characterized by a frequency-duration relationship for use with toxicity data to assess the frequency of acute and chronic toxic conditions for aquatic organisms. The CMRA methodology is comprised of four components: the ARM model is used to simulate pesticide loading to the stream; the EXPLORE model (Baca et al., 1973) simulates stream hydraulics; the SERATRA model (Onishi and Wise, 1979) simulates instream sediment transport, contaminant decay mechanisms, and sediment-contaminant interactions; and the FRANCO model (Olsen and Wise, 1979) performs frequency analyses of the contaminant concentration time series in order to assess the relative occurrence of acute and chronic toxic conditions.

Since both HSPF and CMRA include the ARM model functions and identical statistical capabilities, there is some duplication in the models. As part of this work, HSPF was modified to include the basic SERATRA and FRANCO model capabilities in order to provide a single comprehensive system to analyze water quality and toxic conditions for assessing the aquatic impact of candidate BMPs.

SECTION 2

HISTORICAL DEVELOPMENT OF HSPF

HSPF is the latest product resulting from some 20 years of process research and model development, testing, refinement, and application. The initial 10 years of this research effort involved the development of the Stanford Watershed Model (Crawford and Linsley, 1966) and the Hydrocomp Simulation Program (Hydrocomp, 1969); these two models provided the basic theory and framework for the continuous simulation of hydrologic and hydraulic processes in HSPF. During the second decade of development (1970's), water quality processes were superimposed on the relevant transport components. Under the sponsorship of the EPA Athens Environmental Research Laboratory, extensive model development and associated data collection was performed in an effort to develop effective tools for analyzing agricultural runoff problems and control practices. This 10 year program which lead to development of HSPF has been described by Barnwell and Johanson (1981), from which the remainder of this section has been taken, essentially verbatim.

The concept of a simulation model with the scope of HSPF grew out of a need identified in the late 1960's and early 1970's to simulate pesticide movement on the land surface. Figure 2.1 illustrates the history of the model development and testing program and complementary data collection program that has contributed directly to HSPF. The early work in this program incorporated two approaches, one using distributed parameter hydrology and the other a lumped parameter model. The distributed parameter model called SCRAM (Simulation of Contaminant Reactions and Movement), is described by Adams and Kurisu (1976). SCRAM required two hours of IBM 360/145 CPU time to simulate a 4-month growing season, thus limiting its utility as a management tool. The lumped parameter model, PTR (Pesticide Transport and Runoff), was developed for EPA by Crawford and Donigian (1973). PTR "piggybacks" applied pesticide onto the movement of water and sediment as predicted by the Stanford Watershed Model (as noted above). Overland sediment transport in PTR is based on work done by Negev (1967). Both SCRAM and PTR incorporated semi-empirical process descriptions of pesticide transport and fate to simulate adsorption/desorption, volatilization, and degradation (microbial, chemical, and photochemical).

Modifications, testing, and further development of PTR produced the Agricultural Runoff Management (ARM) model (Donigian and Crawford, 1976). ARM simulates runoff, snow accumulation and melt, sediment loss, pesticide-soil interactions, and soil nutrient transformations. ARM was further improved (Donigian et

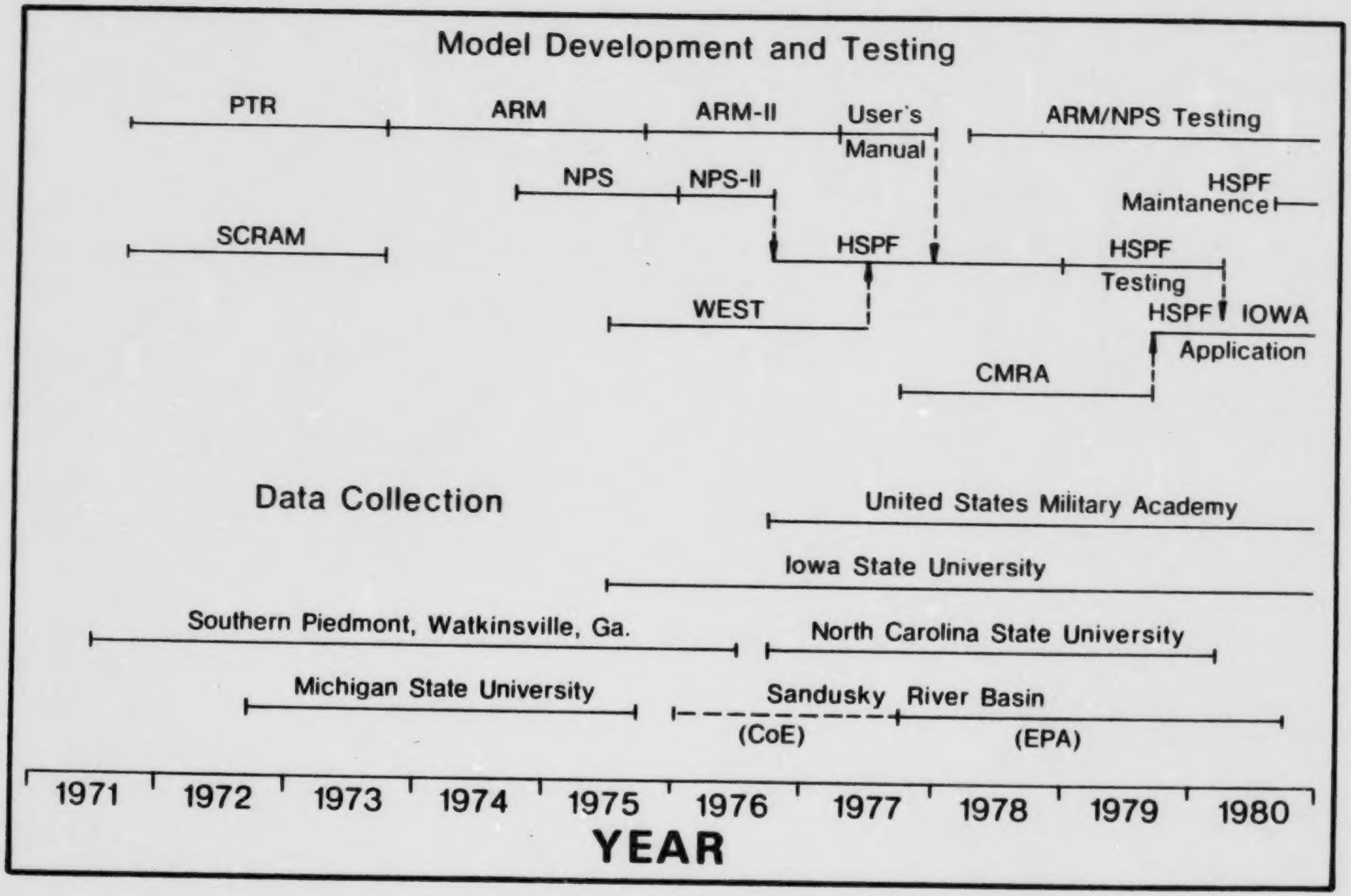


Figure 2.1 Athens Environmental Research Laboratory Model Development, Testing, and Data Collection Program.

al., 1977) through refinement of algorithms related to soil moisture and temperature, soil erosion, pesticide degradation, nutrient transformations and plant nutrient uptake and tested on watersheds in Georgia and Michigan.

During the development of ARM, it was recognized that a simpler version of the model using algorithms compatible with current urban models such as SWMM (Metcalf and Eddy et al., 1971) and STORM (Hydrologic Engineering Center, 1975) was needed. Thus the Nonpoint Source (NPS) model (Donigian and Crawford, 1976) was developed. A major difference in NPS and the other urban models was the capability for continuous simulation and more detailed algorithms for snow accumulation and melt and for sediment transport. STORM and recent versions of SWMM have also included the continuous simulation approach. As in ARM, the hydrologic algorithms in NPS are based on the Stanford Watershed Model and the Hydrocomp Simulation Program (HSP). The simulation of non-point pollutants is based on sediment as a pollutant indicator. Initial testing of NPS was performed on three urban watersheds in North Carolina, Wisconsin, and Washington. Later testing (Donigian and Crawford, 1977) of the model evaluated its ability to simulate nutrient loadings in surface runoff from urban and agricultural watersheds.

Although the information on edge-of-stream nonpoint loads is of major importance in environmental planning, management decisions should consider impacts in the aquatic environment. Thus the HSPF project was initiated to provide the capability to continuously simulate the dynamics of river basins and to generate detailed statistical information on the impacts and system response of implementing various basin-scale water quality management decisions. Also, the ability to generate a continuous time series of pollutant levels in receiving waters provides an interface between water quality and toxicity considerations.

HSPF (Johanson et al., 1980) evolved from experience gained with the Hydrocomp Simulation Package (HSP). A Time Series Management System was incorporated to enable the investigator to cope with the enormous volume of simulation results. The HSP channel routing and water quality algorithms were linked with the ARM/NPS land surface runoff modules and a simple instream sediment transport algorithm based on experience gained through development of the Watershed Erosion and Sediment Transport (Leytham and Johanson, 1979) model was incorporated. The water quality algorithms include BOD/DO dynamics; carbon, nitrogen, and phosphorus cycles; suspended and attached phytoplankton; and one species of zooplankton.

As noted above, as part of the modeling analyses in the Iowa FEP the basic capabilities of the CMRA methodology have been incorporated into HSPF. The added capabilities include expanded sediment transport options, instream pesticide attenuation by specific mechanisms (e.g., biodegradation, volatilization, photolysis), instream sediment-pesticide interactions, and expanded statistical capabilities for analysis of chemical concentration data to allow risk and exposure assessment for aquatic organisms (Johanson et al., 1981).

SECTION 3

HSPF OVERVIEW

HSPF consists of a set of modules arranged in a hierarchical structure, which perform continuous simulation of a comprehensive range of hydrologic and water quality processes. The model framework incorporates the concepts of top-down structure and uniform data structures and programming conventions which allow the user to simulate a wide array of land and stream processes without the problems of logic and data incompatibility which are often encountered in large-scale modeling efforts. A major portion, perhaps one third to one half, of the human effort associated with application of a continuous simulation model is associated with data management. The HSPF system recognizes the central importance of effective data storage, transfer, and manipulation. Consequently, HSPF software is organized around a sophisticated time series management system operating on direct access principles. The simulation modules draw input from a Time Series Store (TSS) and are capable of writing output to it. Details of the HSPF software hierarchy and data management system are available in the users manual (Johanson et al., 1981).

3.1 Current Modules

The operating modules of HSPF are either "application modules" or "utility modules". Application modules simulate processes which occur in the real world, while utility modules perform operations on the time series which are peripheral to the simulation of physical processes (e.g., data input, plot generation, statistical analysis). HSPF currently contains three application modules - PERLND, IMPLND, and RCHRES - and six utility modules - COPY, PLTGEN, DISPLY, DURANL, GENER, and MUTSIN. Each of these modules is summarized in Figure 3.1 and is briefly discussed below. An expanded discussion of components of the PERLND and RCHRES modules which are critical to predicting water quality from agricultural nonpoint source pollution is provided following the general summary of simulation capabilities for the nine operating modules. Module descriptions are extracted from HSPF summary papers (Grimsrud et al., 1980; Barnwell and Johanson, 1981) and updated to reflect enhancements resulting from current work performed as part of HSPF Iowa study and the continuing HSPF maintenance and support work by EPA-Athens.

Module PERLND simulates a pervious land segment with homogeneous hydrologic and climatic characteristics. The simulation of snow accumulation and melt is based on an energy balance approach (Anderson, 1968). Water movement is modeled along three flow paths - overland flow, interflow and groundwater flow - in the

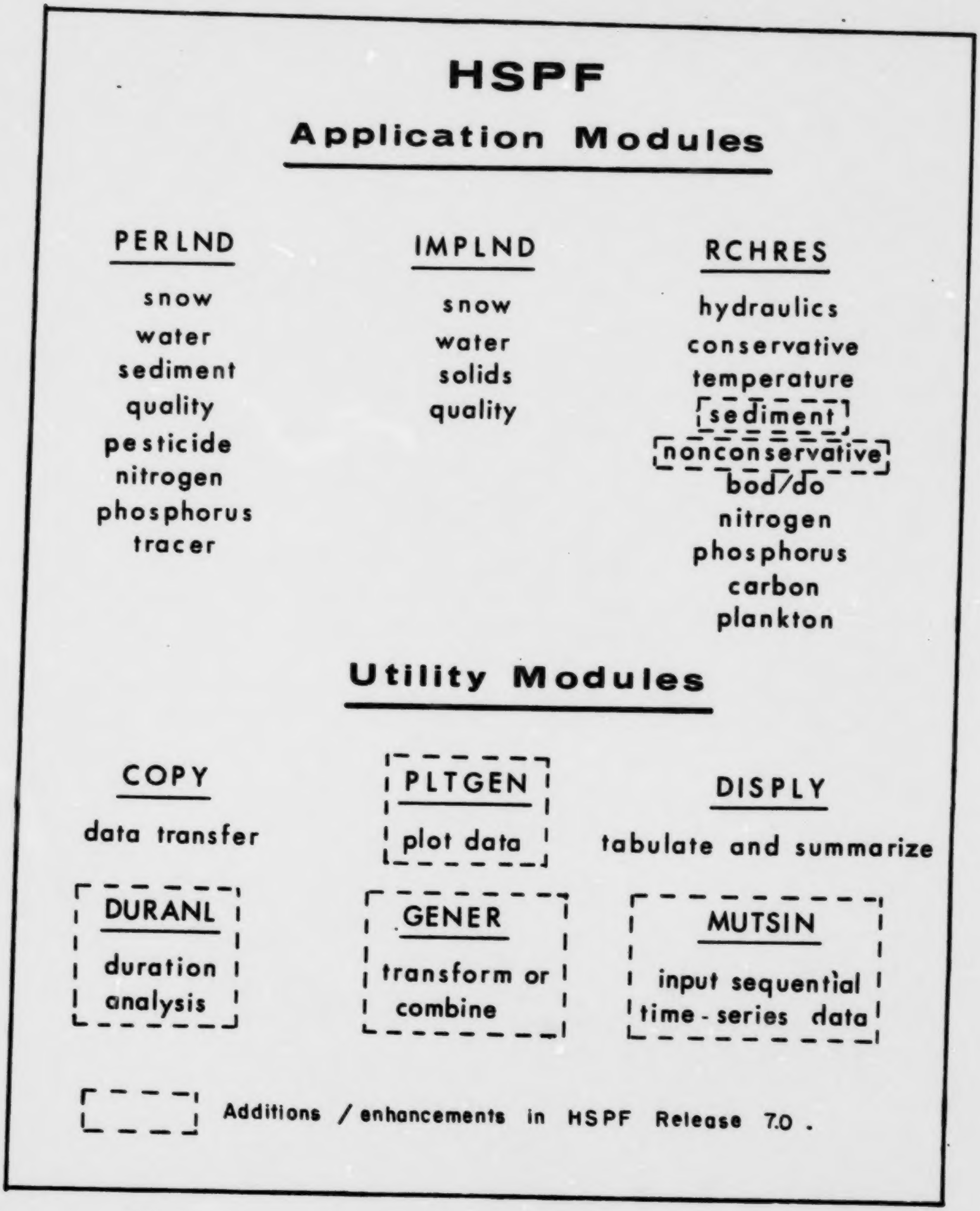

HSPF
Application Modules
PERLND
snow
water
sediment
quality
pesticide
nitrogen
phosphorus
tracer
IMPLND
snow
water
solids
quality
RCHRES
hydraulics
conservative
temperature
sediment
nonconservative
bod/do
nitrogen
phosphorus
carbon
plankton
Utility Modules
COPY
data transfer
PLTGEN
plot data
DISPLY
tabulate and summarize
DURANL
duration analysis
GENER
transform or combine
MUTSIN
input sequential time-series data
Additions / enhancements in HSPF Release 7.0 .

Figure 3.1 HSPF Application and Utility Modules

manner of the Stanford Watershed Model. Erosion processes include sediment detachment by rainfall splash and man's influence and transport by overland flow. Scour in rills and gullies is also considered. Water quality constituents may be simulated in the fashion of the NPS model using simple relationships with sediment and water yield or by using the detailed algorithms for pesticides and nutrients as in the ARM model.

Module IMPLND is designed to simulate impervious land segments where little or no infiltration occurs. Algorithms are similar to PERLND except that no water movement occurs by interflow or goundwater flow. Solids are simulated using accumulation and removal relationships in the manner of urban models such as SWMM and STORM. Water quality constituents are simulated using empirical relationships with solids and water yield.

Module RCHRES simulates the processes that occur in a single reach of an open channel or a completely mixed lake. Hydraulic behavior is modeled using the kinematic wave assumption. The outflow of an element may be distributed across several targets that might represent normal outflows, diversions, and multiple gates on a reservoir. Temperature is simulated using a heat balance approach. Sediments are simulated as three components - sand, silt, and clay. Either power relationships to flow or empirical relationships (Toffaleti or Colby formulations; Vanoni, 1975) based on hydraulic properties can be used. Conservative and nonconservative constituents are simulated in a manner that allows maximum user flexibility. Processes modeled for generalized nonconservatives include decay by instream processes; production of one quality constituent as a result of decay of another constituent; adsorption/desorption to sediment; and advection, deposition, and scour of sediment associated constituents. The primary dissolved oxygen and biochemical oxygen demand balances are simulated in the traditional manner, with provisions for decay, settling, benthal sources, reaeration, etc. The primary nitrogen balance is modeled as sequential reactions from ammonia through nitrate. Denitrification is also considered. Both nitrogen and phosphorus are considered in modeling three types of plankton - phytoplankton, zooplankton, and attached algae. Dissolved oxygen is considered in modeling plankton and the nitrogen cycle. Hydrogen ion activity (pH) is calculated considering carbon dioxide, total inorganic carbon, and alkalinity.

HSPF's utility modules are designed to give the user maximum flexibility in managing simulation input and output. COPY is used to manipulate time series. The user can change the form of the time series during the COPY operation. A 5-minute rainfall record may be aggregated to an hourly time interval, for example. The PLTGEN module creates a specially formatted sequential file for later access by a stand-alone plot program. DISPLY takes a time series and summarizes the data in a neatly formatted table. Aggregation of the basic data is also possible. DURANL performs a duration and excursion analysis on a time series and computes some elementary statistics. It can answer questions like: "How often does dissolved oxygen stay below 4 mg/l for 4 consecutive hours?" The GENER module is used to transform a time series (A) to produce a new series (C) or to combine two time series (A+B) to create a new one (C). For example, this module is useful if one wants to compute the mass outflow of a constituent from the flow and concentration. The MUTSIN module allows the input to HSPF of sequential time series data generated by another model or the output of HSPF simulation results in a format compatible with input requirements for other models. Thus, the module provides a means for interfacing the HSPF system to other models with a reasonable level of effort.

SECTION 4

MODELING AGRICULTURAL RUNOFF AND ASSOCIATED INSTREAM PROCESSES WITH HSPF

This section provides a brief overview of the overall representation of the fate and movement of agricultural chemicals in HSPF in the runoff, soil, and stream environments. Primary emphasis is placed on the enhanced capabilities and algorithms related to the instream sediment and chemical processes which were incorporated into HSPF during this study. More details on all the algorithms can be found in the HSPF user manual and the predecessor model reports.

4.1 Modeling Soil and Runoff Processes With HSPF PERLND

In HSPF, the Pervious Land Segment module (PERLND) simulates the water quality and quantity processes which occur on pervious land areas, and which provide flow, sediment, and chemical contributions to a stream channel from surface and subsurface sources. Figure 4.1 is the structure chart of the PERLND module showing the component module sections and associated functions. Of primary concern in this study are the SNOW, PWATER, and SEDMNT module sections that include the hydrologic and sediment erosion modeling capabilities, and the agri-chemical module sections (i.e. MSTLAY, PEST, NITR, PHOS, TRACER) that simulate the fate, transformations, and runoff of pesticides, nutrients, and non-reactive tracer chemicals. In HSPF, the ARM Version II algorithms (Donigian et al., 1977; Donigian and Crawford, 1979) were recreated with some additional options and enhancements. The primary differences between HSPF PERLND and ARM II have been summarized by Donigian et al (1983).

Modeling chemical movement over and through the soil. The transport and vertical movement of pesticides and nutrients, as conceived in the PERLND module is indicated in Figure 4.2. Pollutant contributions to the stream can occur from the surface zone, the upper zone, and groundwater zone. Surface runoff is the major transport mechanism carrying sediment, pesticide particles, and adsorbed and dissolved chemicals. The interflow component of runoff can transport dissolved pesticides or nutrients occurring in the upper zone. Vertical chemical movement between the soil zones is the result of infiltrating and percolating water. From the vertical soil layers, uptake and transformation of nutrients and degradation of pesticides is allowed. The active groundwater layer receives percolating water and associated dissolved chemicals which then reach the stream channel with the groundwater flow component.

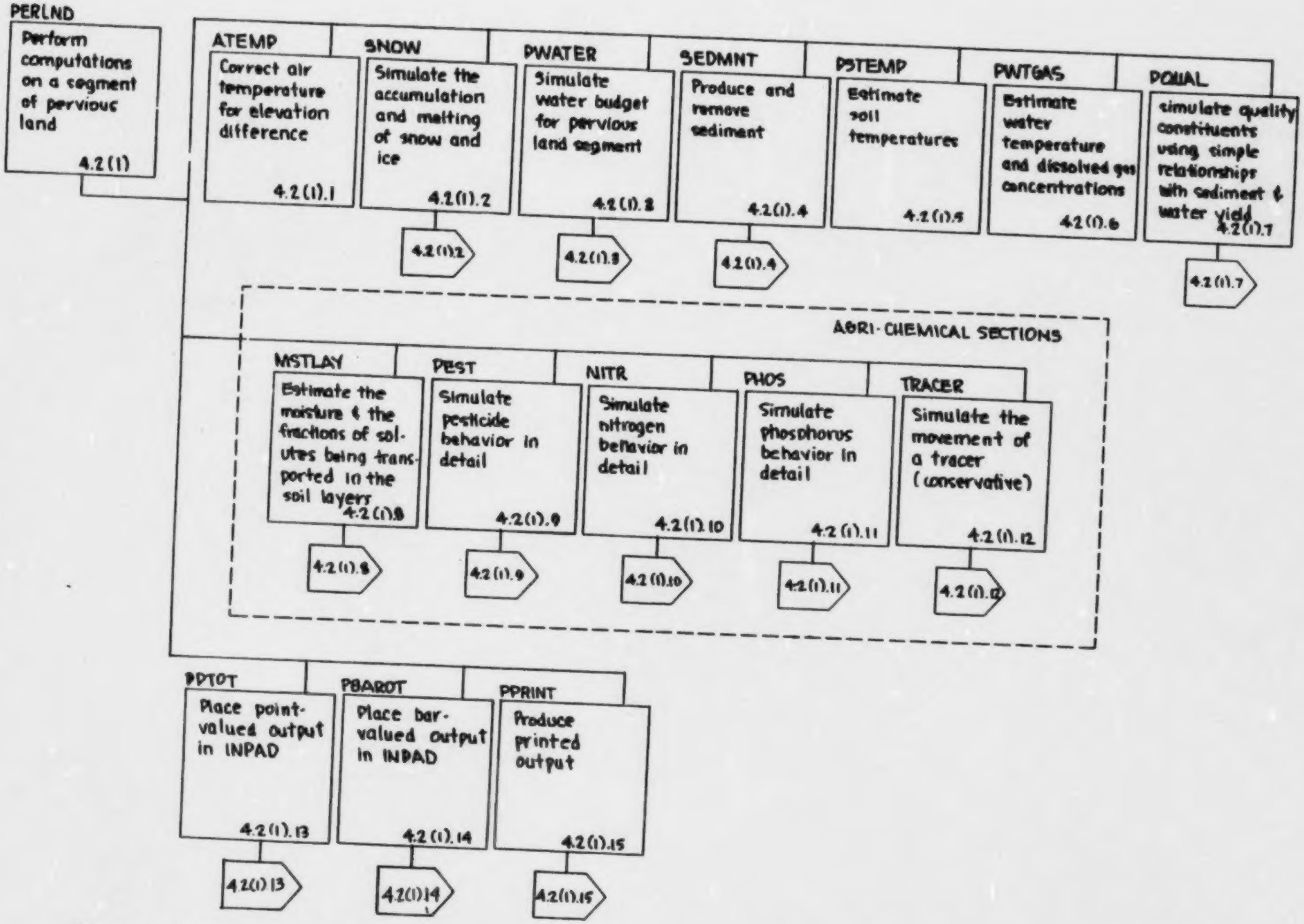

PERLND
Perform computations on a segment of pervious land
4.2(1)
ATEMP
Correct air temperature for elevation difference
4.2(1).1
SNOW
Simulate the accumulation and melting of snow and ice
4.2(1).2
4.2(1).2
PWATER
Simulate water budget for pervious land segment
4.2(1).3
4.2(1).3
SEDMNT
Produce and remove sediment
4.2(1).4
4.2(1).4
PSTEMP
Estimate soil temperatures
4.2(1).5
PWTGAS
Estimate water temperature and dissolved gas concentrations
4.2(1).6
PQUAL
simulate quality constituents using simple relationships with sediment & water yield
4.2(1).7
4.2(1).7
AGRI-CHEMICAL SECTIONS
MSTLAY
Estimate the moisture & the fractions of solutes being transported in the soil layers
4.2(1).8
4.2(1).8
PEST
Simulate pesticide behavior in detail
4.2(1).9
4.2(1).9
NITR
Simulate nitrogen behavior in detail
4.2(1).10
4.2(1).10
PHOS
Simulate phosphorus behavior in detail
4.2(1).11
4.2(1).11
TRACER
Simulate the movement of a tracer (conservative)
4.2(1).12
4.2(1).12
PPTOT
Place point-valued output in INPAD
4.2(1).13
4.2(1).13
PBAROT
Place bar-valued output in INPAD
4.2(1).14
4.2(1).14
PPRINT
Produce printed output
4.2(1).15
4.2(1).15

Figure 4.1 Structure chart for the Pervious Land-Segment Application Module of HSPF.

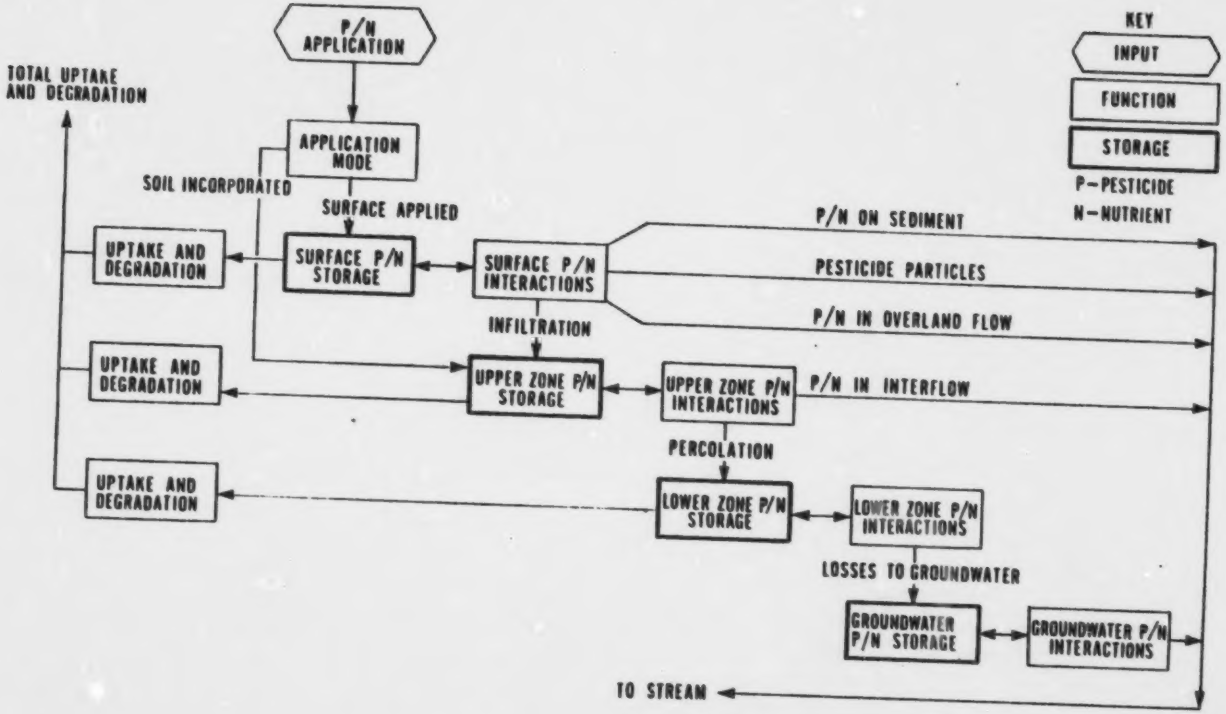

P/N APPLICATION
APPLICATION MODE
SOIL INCORPORATED
SURFACE APPLIED
TOTAL UPTAKE AND DEGRADATION
UPTAKE AND DEGRADATION
SURFACE P/N STORAGE
SURFACE P/N INTERACTIONS
INFILTRATION
UPTAKE AND DEGRADATION
UPPER ZONE P/N STORAGE
UPPER ZONE P/N INTERACTIONS
PERCOLATION
UPTAKE AND DEGRADATION
LOWER ZONE P/N STORAGE
LOWER ZONE P/N INTERACTIONS
LOSSES TO GROUNDWATER
GROUNDWATER P/N STORAGE
GROUNDWATER P/N INTERACTIONS
P/N ON SEDIMENT
PESTICIDE PARTICLES
P/N IN OVERLAND FLOW
P/N IN INTERFLOW
TO STREAM
KEY
INPUT
FUNCTION
STORAGE
P—PESTICIDE
N—NUTRIENT

Figure 4.2 Pesticide (p) and nutrient (n) movement in the PERLND module of HSPF.

In order to simulate vertical movement and transformations of pesticides and nutrients in the soil profile, specific soil layers (and depths) are established so that the total soil mass in each layer can be computed. Total soil mass is a necessary ingredient in the pesticide adsorption/desorption reactions and nutrient transformations. The vertical soil layers simulated in PERLND include the surface, upper, lower, and groundwater zones. The depths of the soil zones are specified by the model input parameters. The surface zone represents a uniform mixing layer for surface-applied chemicals. The upper zone depth corresponds to the depth of incorporation of soil-incorporated chemicals. It also indicates the depth used to calculate the mass of soil in the upper zone whether agricultural chemicals are soil-incorporated or surface-applied.

The lower zone reaches from the bottom of the upper zone to the top of the capillary fringe of the active groundwater layer. The thickness of the groundwater layer corresponds to the thickness of the groundwater aquifer actively contributing to groundwater or base flow in the watershed.

Hydrology simulation. As noted above, the hydrologic simulation methodology in the PERLND module was derived from the ARM model and HSP. The ATEMP, SNOW, and PWATER module sections of HSPF jointly perform the functions of the LANDS subprogram of the other models. Through a linked set of theoretical and empirical mathematical functions, the PWATER module section simulates the land surface and soil processes of the hydrologic cycle including interception, surface detention, soil moisture storage, surface runoff, infiltration, interflow, evapotranspiration, percolation to groundwater, and groundwater outflow. The SNOW module section performs energy (heat) balance calculations based on input meteorologic data to simulate the various physical processes that determine snow accumulation and melt.

Sediment erosion simulation. Module Section SEDMNT simulates the production and removal of sediment from pervious land areas based on the input rainfall, the PWATER simulation of overland flow, and the input model parameters describing the soil characteristics and land surface conditions as affected by agronomic practices. The equations used to produce and remove sediment are based on the ARM and NPS Models. The algorithms representing land surface erosion in these models were derived from a sediment model developed by Negev (1967) and influenced by Meyer and Wischmeier (1969) and Onstad and Foster (1975).

SEDMNT simulates the detachment, attachment, and removal processes involved in sediment erosion from the land surface. Removal of sediment by water is simulated as washoff of detached sediment in storage and scour of the matrix soil. The washoff process involves two parts: the detachment/attachment of sediment from/to the soil matrix and the transport of this sediment. Detachment occurs by rainfall, while attachment occurs only on days without rainfall. Transport of detached sediment is by overland flow. The scouring of the matrix soil includes both pick up and transport by overland flow combined into one process.

Monthly cover values as of the first day of the month are specified by the user to represent protection of the land surface by crop canopy, residues, etc. The model interpolates linearly between the monthly values to evaluate land cover on each day. The kinetic energy of rainfall is effectively dissipated by the land cover with values of 90 to 95 percent of the area. Thus, judicious use of the land cover function allows simulation of various land surface conditions for different practices.

The timing and severity of tillage operations have a controlling effect on the sediment loss from an agricultural watershed. With regard to sediment production, the effect of tillage operations is to increase the mass of detached soil fines available for transport and produce a reasonably uniform distribution of fines across the watershed. Consequently, HSPF allows the user to specify the dates of tillage, planting, or other land-surface disturbing operations. For each of these dates the user can specify a new detached soil fines storage resulting from the operation. At the time of tillage HSPF resets the fines storage to the new value(s) resulting in a new fines distribution across the watershed. The amount of fines storage produced by different tillage operations is related to the depth and extent of the operation and edaphic characteristics.

Pesticide simulation. Using the moisture movement and runoff simulation from section PWATER and the sediment erosion simulation from section SEDMNT, the PEST section simulates the adsorption/ desorption process, vertical movement, decay, and resulting runoff contributions of a pesticide. The process of pesticide adsorption/desorption onto sediment particles is a major determinant of the amount of pesticide loss that will occur. This process establishes the division of available pesticide between the water and sediment phases, and thus specifies the relative amounts of pesticide transported in solution and on sediment.

In section PEST, HSPF allows the user to simulate the adsorption/desorption process with either an equilibrium isotherm or separate first-order rate constants. The input adsorption parameters and rate constants can be specified separately for each soil layer. The rate constants can be adjusted for soil temperature (either simulated or observed) based on a modified Arrhenius relationship.

Attenuation of applied pesticides, through volatilization and degradation processes, is critical to the accurate simulation of pesticide runoff because these mechanisms control the amount of chemical available for transport. These processes are not well understood and are topics of continuing research. To approximate the pesticide attenuation following application, HSPF includes a first-order attenuation function that allows the use of different degradation rates for separate time periods after application. The function calculates the combined degradation of pesticides by volatilization, microbial degradation, and other attenuation mechanisms. Different degradation rates can be specified for each soil layer. This capability allows the use of higher decay rates in the surface layer where the pesticide may undergo volatilization, photochemical decay, and microbial decay, and lower rates in the subsurface layers where microbial degradation is the primary mechanism.

Nutrient simulation. Nutrient simulation by the NITR and PHOS module sections of HSPF attempts to represent the reactions and transformations of nitrogen and phosphorus compounds in the soil profile as a basis for predicting the nutrient content of agricultural runoff. As in the PEST section, moisture and sediment movement values are transferred from the associated modules to provide the moisture storage and transport values needed for the nutrient simulation. The nutrient model primarily assumes first-order reaction rates and is derived from work by Mehran and Tanji (1974), and Hagin and Amberger (1974). The processes simulated include immobilization, mineralization, nitrification/denitrification, plant uptake, and adsorption/desorption (for which an equilibrium isotherm option is available). In the model, fertilizer, plant residue, or animal waste is applied in their chemical form (NH4, NO3, PO4, Cl, and organic N and P) to the land surface or incorporated into the soil.

The NITR section simulates nutrient movement in the watershed by water or sediment. Transformations of nutrients determine the nutrient forms in each soil layer and their resulting susceptibility to movement. Nutrient transport processes are simulated only to the extent that is needed to predict runoff quality and quantity. The model does not consider the generally secondary movement of soil chemicals by concentration and thermal gradients. However, it does model the lateral and downward transport of chemicals by water from the soil zones. Lateral transport of nutrients towards the stream can occur from the surface and upper zone storages. Inflow of nutrients to the groundwater zone and nutrient transformations in the groundwater are modeled as a basis for predicting the outflow of dissolved constituents with groundwater flow.

Soil temperature is presently the only environmental factor that is modeled as affecting the reaction rates, with the exception that the transformations are stopped entirely at very low moisture levels. All input parameters are specified for each soil layer; thus variations in characteristics of the soil profile can be accommodated by varying the reaction rates for the different soil layers.

4.2 Modeling Instream Sediment Transport and Chemical Fate Processes

In HSPF, the Reach/Mixed Reservoir module (RCHRES) simulates the water quality and quantity processes which occur within the stream channel. Figure 4.3 is the structure chart of the RCHRES module showing the component module sections and associated functions. Of primary interest in this section are the SEDTRN and GQUAL module sections which include the instream sediment transport and chemical fate process simulation capabilities. These module sections are the result of the recent incorporation of the SERATRA model capabilities into HSPF. Module section SEDTRN replaces the previous simplistic sediment transport module section SED, and GQUAL replaces section FSTORD which modeled first-order decay behavior for chemical constituents not involved in any other reactions in RCHRES. The processes previously simulated by SED and FSTORD are special cases of the current SEDTRN and GQUAL capabilities, respectively. This section of the report discusses the particular algorithms which simulate instream sediment transport and general contaminant transport/reaction processes in HSPF as a result of incorporation of SERATRA capabilities.

Sediment transport simulation. Module Section SEDTRN simulates the transport, deposition, and scour of inorganic sediment in free-flowing reaches and mixed reservoirs. Figure 4.4 shows the principal state variables and fluxes with which section SEDTRN deals.

Both the transport characteristics and the adsorptive capabilities of sediment vary significantly with particle size. Consequently, HSPF divides the inorganic sediment load into three components (sand, silt, and clay), each with its own properties. As Figure 4.4 indicates, the same materials fluxes are modeled for all three fractions of sediment. Only the methodology used to determine fluxes between suspended storage and bed storage differ.

HSPF assumes that scour or deposition of inorganic sediment does not affect the hydraulic properties of the channel. Furthermore, it is assumed that sand, silt, and clay desposit in different areas of the RCHRES bed; consequently, the deposition or scour of

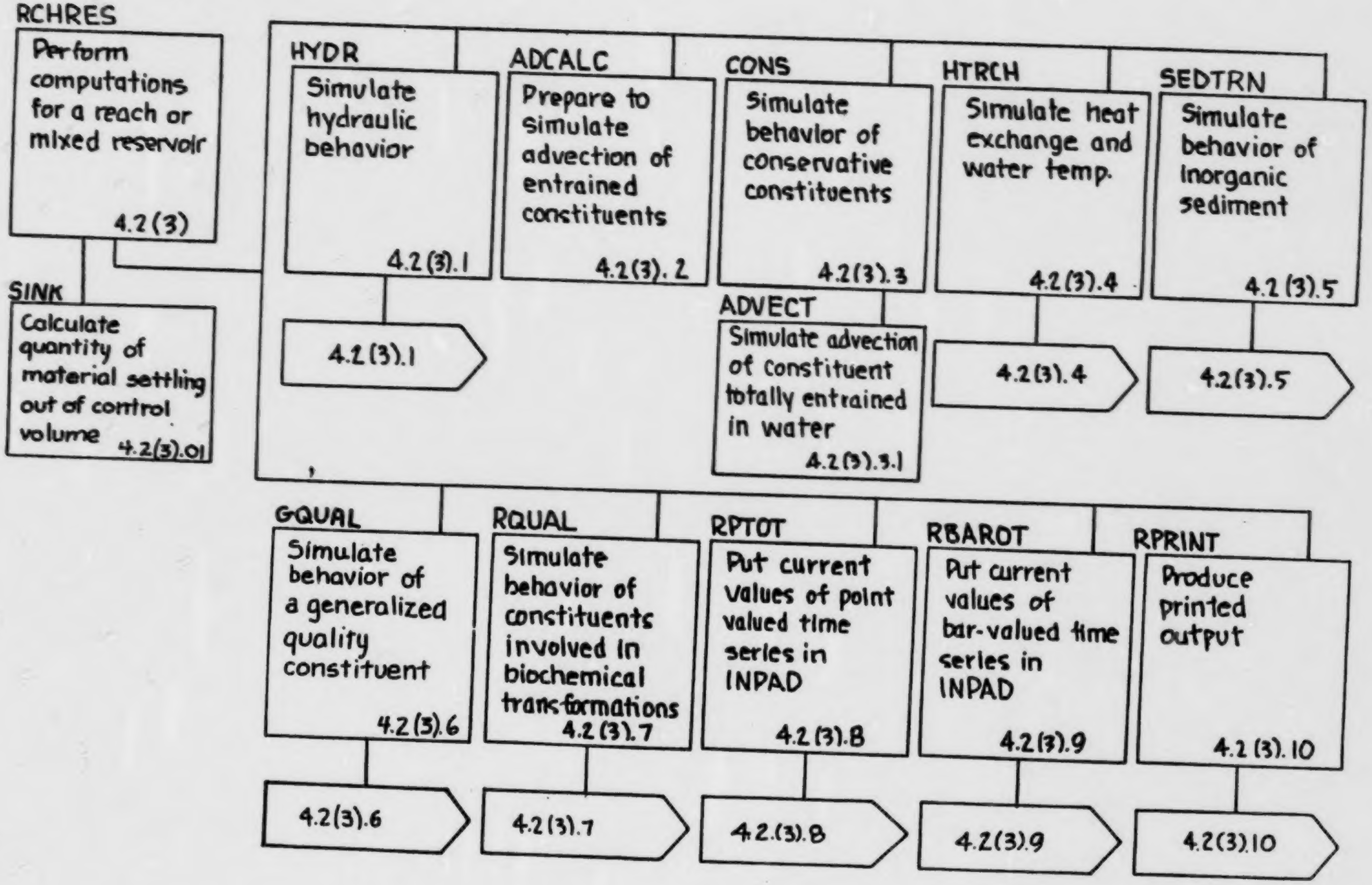

RCHRES
Perform computations for a reach or mixed reservoir
4.2(3)
SINK
Calculate quantity of material settling out of control volume
4.2(3).01
HYDR
Simulate hydraulic behavior
4.2(3).1
4.2(3).1
ADCALC
Prepare to simulate advection of entrained constituents
4.2(3).2
CONS
Simulate behavior of conservative constituents
4.2(3).3
ADVECT
Simulate advection of constituent totally entrained in water
4.2(3).3.1
HTRCH
Simulate heat exchange and water temp.
4.2(3).4
4.2(3).4
SEDTRN
Simulate behavior of inorganic sediment
4.2(3).5
4.2(3).5
GQUAL
Simulate behavior of a generalized quality constituent
4.2(3).6
4.2(3).6
RQUAL
Simulate behavior of constituents involved in biochemical transformations
4.2(3).7
4.2(3).7
RPTOT
Put current values of point valued time series in INPAD
4.2(3).8
4.2.(3).8
RBAROT
Put current values of bar-valued time series in INPAD
4.2(3).9
4.2(3).9
RPRINT
Produce printed output
4.2(3).10
4.2(3).10

Figure 4:3 Structure chart for the Reach/Mixed Reservoir Application Module of HSPF.

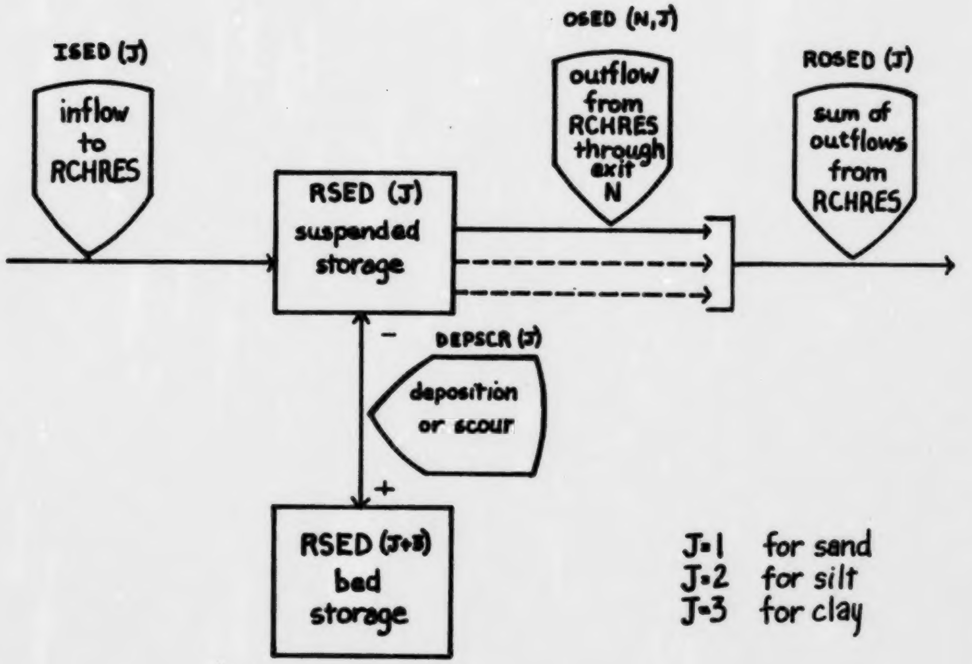

ISED (J)
inflow to RCHRES
RSED (J) suspended storage
OSED (N,J)
outflow from RCHRES through exit N
ROSED (J)
sum of outflows from RCHRES
−
DEPSCR (J)
deposition or scour
+
RSED (J+3) bed storage
J=1 for sand
J=2 for silt
J=3 for clay

Figure 4.4 Flow diagram of inorganic sediment fractions in the SEDTRN Section of the RCHRES Application Module.

each material is not linked to the other fractions (i.e., "armoring" is not modeled). Longitudinal movement of bed sediments is not modeled. It should be noted that the PERLND module of HSPF simulates removal of total inorganic sediment due to washoff from the land surface and erosion from gullies. The model user must divide the total sediment load from PERLND into the three components (sand, silt, and clay) so that this material can be routed through the channel system in the RCHRES module.

The deposition, scour and transport process of cohesive sediments (silt and clay) are simulated separately from sand. The modeling effort consists of two steps. First, advective transport is performed, and then deposition or scour is calculated based on the bed shear stress and the Krone (1962) and Partheniades (1962) equations. Exchange of cohesive sediments with the bed is dependent upon the shear stress exerted upon the bed surface. The shear stress within the RCHRES is calculated in the HYDR section. Whenever shear stress (TAU) in the RCHRES is less than the user-supplied critical shear stress for deposition (TAUCD), deposition occurs; whenever shear stress is greater than the user-supplied critical shear stress for scour (TAUCS), scouring of cohesive bed sediments occurs. The concentration of suspended sediment lost to deposition during a simulation interval (e.g. hour) is derived from a simplification of Krone's (1962) equation:

$$\mathrm{DEPCONC} = \mathrm{CONC}*(1.0 - \mathrm{EXP}((-\mathrm{W}/\mathrm{AVDEPM})*(1.0 - \mathrm{TAU}/\mathrm{TAUCD})) \qquad (4.1)$$

where:

CONC = concentration of suspended sediment fraction at start of interval (mg/l)
W = settling velocity for sediment fraction (m/hr)
AVDEPM = average depth of water in RCHRES in meters
TAU = shear stress (lb/ft2 or kg/m2)
TAUCD = critical shear stress for deposition (lb/ft2 or kg/m2)

The concentration of suspended sediment added to suspension by scour during a simulation interval is derived from a modification of Partheniades' (1962) equation:

$$\mathrm{SCRCONC} = \mathrm{M}/\mathrm{AVDEPM}*1000*(\mathrm{TAU}/\mathrm{TAUCS} - 1.0) \qquad (4.2)$$

where:

M = erodibility coefficient in kg/m2.hr
AVDEPM = average depth of water in meters
1000 = conversion from kg/m3 to mg/l
TAU = shear stress (lb/ft2 or kg/m2)
TAUCS = critical shear stress for scour (lbs/ft2 or kg/m2)

Erosion and deposition of sand, or noncohesive sediment, is affected by the amount of sediment the flow is capable of carrying. If the amount of sand being transported is less than the flow can carry for the hydrodynamic conditions of the RCHRES, sand will be scoured from the bed. This occurs until the actual sand transport rate becomes equal to the carrying capacity of the flow or until the available bed sand is all scoured. Conversely, deposition occurs if the sand transport rate exceeds the flow's capacity to carry sand.

HSPF allows the calculation of sand transport capacity for a RCHRES by any one of three methods. These are:

1. The Toffaleti method, in which empirical expressions relating velocity and sediment concentration to the hydraulic properties are used to derive equations for sand transport capacity;
2. The Colby method in which empirical relationships between the transport capacity and hydraulic properties are also utilized. The final value is the result of corrections due to hydraulic radius, velocity, mean diameter of bed sediment, water temperature, and fine sediment load concentration. In general, the correction factors are determined by interpolating within a matrix of values.
3. Power function method in which sand transport capacity is calculated using an input power function of velocity.

4.3 Generalized chemical constituent simulation

Module section GQUAL simulates the behavior of a generalized quality constituent. The constituent which is modeled may be present in the RCHRES only in a dissolved state, or it may also be sediment-associated. If the generalized quality constituent, which will be called a "qual" throughout this discussion, is not associated with sediment, module section GQUAL only considers the following processes:

1. Advection of dissolved material

2. Decay processes. One or more of the following can be modeled:
   a. hydrolysis
   b. oxidation by free radical oxygen
   c. photolysis
   d. volatilization
   e. biodegradation
   f. generalized first-order decay

3. Production of one generalized quality constituent as a result of decay of another generalized quality constituent by any of the listed decay processes, i.e.

parent-daughter reactions. This capability is included to allow for situations in which the decay products of a chemical are also of interest to the user.

The following additional processes are considered if the generalized quality constituent being modeled is sediment-associated:

4. Advection of adsorbed suspended material
5. Deposition and scour of adsorbed material
6. Decay of suspended and bed material
7. Adsorption/desorption between dissolved and sediment-associated phase.

The first portion of GQUAL evaluates the nature of the data which will be used for the GQUAL simulation. Since it is anticipated that some users of section GQUAL will be using this section independently of many of the other sections of the RCHRES application module, a variety of data types are allowed. In particular, most data required for simulation of individual decay processes can be supplied in the form of a single constant, 12 monthly constants, a time series value, or in cases where the data value is calculated in another active section of RCHRES, the last computed value may be used. Data types which may be obtained from any one of these sources include:

1. water temperature
2. pH (for hydrolysis)
3. free radical oxygen (for oxidation)
4. total suspended sediment (for photolysis)
5. phytoplankton (for photolysis)
6. cloud cover (for photolysis)
7. wind (for volatilization on lakes)

GQUAL utilizes six routines to perform the simulation of a generalized quality constituent. These six routines and their functions are:

1. DDECAY - simulate decay of dissolved material
2. OXREA - compute oxygen reaeration rate (used in simulation of volatilization)
3. ADVECT - simulate advection of dissolved material
4. ADVQAL - simulate advection of sediment-associated material
5. ADECAY - simulate decay of sediment-associated material
6. ADSDES - simulate exchange of materials due to adsorption and desorption.

DDECAY simulates the degradation of generalized quality constituents by chemical and/or biological means. Six processes are considered:

1. hydrolysis
2. oxidation by free radical oxygen
3. photolysis
4. volatilization
5. biodegradation
6. generalized first-order decay

The primary reference used in the development of this subroutine was the SERATRA User's Manual (Onishi and Wise, 1979). As was the case with the SERATRA model, HSPF includes detailed degradation methods only for the dissolved state of the quality constituent (qual); decay of qual material in the adsorbed state is handled by a lumped first-order decay function in ADECAY. Formulations of the degradation processes are based on studies conducted by Smith et al. (1977), Zepp and Cline (1977), Falco et al. (1976), and Mill et al. (1980). Users who are familiar with the formulations utilized in SERATRA should note that modifications have been made in DDECAY to the algorithms which represent photolysis and volatilization. These changes are outlined in the following description of methods. An additional modification to SERATRA which should be noted is that all degradation processes modeled in DDECAY contain a temperature correction factor.

<u>Hydrolysis</u>. Hydrolysis may be defined as a reaction taking place in water in which a compound is transformed as a result of a reaction with water. In HSPF, the equation presented by Smith et al., (1977) is modified to include a temperature correction factor and rewritten as:

```
KHYD = (KA*10.0**(-PHVAL) + KB*10.0**(PHVAL - 14.0) + KN)*
       THHYD**TW20                                        (4.3)
```

where:

KHYD = hydrolysis rate constant for qual adjusted for pH and water temperature conditions of RCHRES
KA = hydrolysis rate coefficient for qual in acidic solution (pH5)
KB = hydrolysis rate coefficient for qual in basic solution (pH9)
KN = hydrolysis rate coefficient for qual in neutral solution (pH7)
PHVAL = pH of water in RCHRES
THHYD = temperature correction parameter for hydrolysis
TW20 = TW (water temperature in degrees C) - 20.0

Oxidation by Free Radical Oxygen. In HSPF, oxidation is defined as reaction of a chemical with oxidants in solution in which the oxidants are formed by reactions of dissolved or suspended natural materials in solution. The rate of oxidation of dissolved qual is expressed as a function of free radical oxygen concentration and water temperature:

$$KROX = KOX*ROC*(THOX**TW20) \quad (4.4)$$

where:

KROX = oxidation rate constant for qual adjusted for free radical oxygen concentration and water temperature
KOX = base oxidation rate coefficient for qual
ROC = free radical oxygen concentration (moles/l)
THOX = temperature correction parameter for oxidation
TW20 = TW (water temperature in degrees C) - 20.0

Photolysis. Photochemical transformation of chemicals can occur when energy in the form of light is absorbed by a molecule, placing it in an excited state from which reaction can occur. Direct photolysis of chemicals occurs when the chemical molecule itself absorbs light and undergoes reaction from its excited state. Indirect photolysis occurs when another chemical species, called a sensitizer, absorbs light and the sensitizer transfers energy from its excited state to another chemical, which then undergoes reaction. There are many types of photochemical reactions, including oxidation, reduction, hydrolysis, substitution, and rearrangement. In practice it is possible to measure the rate constant for photochemical reaction or a reaction quantum yield without knowing the types of reactions which are occurring (Mill et al., 1980). The formulation of photolysis developed for HSPF is intended to measure the net degradation of a generalized quality constituent which results from photochemical reactions.

The basic equation for rate of loss of a qual in dilute solution in an environmental water body due to absorbance of light of wavelength lambda is given by:

$$KPHOL = ((PHI*INLITL)/DEP)*FSLAM*FQLAM \quad (4.5)$$

where:

KPHOL = rate of loss of qual due to photolysis from absorption of light of wavelength lambda
PHI = reaction quantum yield for photolysis of qual expressed in moles/einstein
INLITL = incident light intensity of wavelength lambda in einsteins/cm2.day
DEP = depth of water in m
FSLAM = fraction of light absorbed by the system
FQLAM = fraction of absorbed light that is absorbed by qual

This equation is complicated by correction factors due to the absorbance of light by suspended sediment and phytoplankton. In addition, the solution technique outlined by Mill and implemented in HSPF uses seasonal day-averaged, 24-hour light intensity values for 18 wavelength intervals from 300 nm to 800 nm. To obtain the final expression for rate of loss of qual due to photolysis, the above equation is summed over the 18 wavelength intervals and further corrected for surface shading and water temperature.

For simulation intervals of less than 24 hours, photolysis is assumed to occur only between 6:00 AM and 6:00 PM during approximate daylight hours. In order to obtain a solution which is reasonably consistent with the input seasonal, day-averaged, 24-hour light intensity values, the daily light intensity is assumed to be uniformly distributed over the 12 hours from 6:00 AM to 6:00 PM. Consequently, calculated photolysis rates are doubled during daylight hours and set equal to zero for non-daylight hours.

Volatilization. Volatilization of a chemical that is dissolved in water is defined as the transport of the chemical from the water to the atmosphere. The concentration of the chemical in water decreases even though a transformation does not occur.

In HSPF, the volatilization rate of a qual is tied to the oxygen reaeration coefficient:

$$KVOL = KOREA*CFGAS \qquad (4.6)$$

where:

KVOL = rate of loss of qual from water due to volatilization

KOREA = oxygen reaeration coefficient calculated in section OXRX

CFGAS = ratio of volatilization rate of qual to oxygen reaeration rate, an input parameter.

Biodegradation. Biodegradation is one of the most important processes for transformation of chemical compounds when they enter into natural environments. Many organic chemicals are used by living cells for carbon and energy sources. Microorganisms metabolize a wide variety of organic compounds, including many man-made chemicals (Mill et al., 1980). The rate of biodegradation of a dissolved qual is expressed as a function of the concentration of biomass which degrades the qual (BIO) and water temperature:

```
KBIO = KBMASS*BIO*(THBIO**TW20)                                    (4.7)
```

where:

KBIO = biodegradation rate constant for qual adjusted for biomass concentration and water temperature
KBMASS = base biodegradation rate coefficient for qual
BIO = concentration of biomass that is involved in qual degradation
THBIO = temperature correction parameter for biodegradation
TW20 = TW (water temperature in degrees C) - 20.0

Generalized First-Order Decay. Generalized first-order decay of the dissolved state of a qual may be simulated in addition to, or instead of, the individual decay processes outlined above. The equation used to calculate rate of decay is:

```
KGEN = KGEND*THGEN**TW20                                           (4.8)
```

where:

KGEN = generalized first-order decay rate for a qual corrected for temperature
KGEND = base first-order decay rate for a qual
THGEN = temperature correction parameter for first-order decay

ADVQAL simulates the advective processes for the quality constituent (qual) attached to one sediment size fraction. Processes handled in this subroutine include:

1. Inflow to the RCHRES of qual attached to suspended sediment.

2. Migration of qual from suspension in the water to the bed as a result of deposition of the sediment to which the qual is adsorbed.

3. Migration of qual from the bed into suspension in the water as a result of scour of the bed sediments to which the qual is adsorbed.

4. Outflow from the RCHRES of qual attached to suspended sediment.

The movement of adsorbed qual is completely dictated by the movement of the sediment to which it is attached. All fluxes of adsorbed qual are expressed as the product of the flux of a sediment fraction (sand, silt, or clay) and the concentration of qual associated with that fraction (expressed in mg per mg of sediment). Likewise, storages of adsorbed qual are expressed as the product of the sediment fraction storage and the associated concentration of qual.

ADECAY is a generalized subroutine which calculates the amount of decay experienced by a generalized quality constituent (qual) adsorbed to inorganic sediment. This subroutine is called twice (once for decay on suspended sediment and once for decay on bed sediment) for each generalized quality constituent which is sediment-associated. HSPF assumes that the decay rate of a particular adsorbed qual is the same for all fractions of sediment (sand, silt, and clay), but may be different for suspended sediment than it is for bed sediment.

ADSDES simulates the exchange of a generalized quality constituent (qual) between the dissolved state and adsorbed state. Kinetic equilibrium between dissolved state and six adsorption sites is modeled: suspended sand, silt, and clay; and bed sand, silt, and clay.

The basic equation (Onishi and Wise, 1979) for the transfer of a chemical between the dissolved state and an adsorbed state on sediment type J is:

$$-d(RSEDJ*SQALJ)/dt + RSEDJ*KJT*(KDJ*DQALJ - SQALJ) = 0 \tag{4.9}$$

where:

RSEDJ = total quantity of sediment type J in the RCHRES expressed in mg.ft3/l or mg.m3/l
SQALJ = concentration of qual on sediment type J expressed in mg/mg
DQALJ = concentration of dissolved qual in mg/l
KDJ = distribution coefficient between dissolved state and sediment type J expressed in liters/mg (equilibrium adsorbed concentration/dissolved concentration)
KJT = temperature corrected transfer rate between dissolved state and sediment type J

Thus, adsorption of a qual by sediment or desorption from sediment is assumed to occur toward an equilibrium condition with transfer rate KJT if the particulate qual concentration differs from its equilibrium value. The previous equation is actually 6 equations (one for each sediment type J) with 7 unknowns (DQAL and 6 values of SQALJ). The necessary seventh equation is that of conservation of material.

SECTION 5

HSPF CALIBRATION/VERIFICATION IN FOUR MILE CREEK

The process of applying HSPF to a complex agricultural watershed to evaluate agricultural nonpoint source pollution and resulting water quality involves the integrated modeling of soil processes, runoff, and instream processes discussed above. Calibration and verification efforts are needed to evaluate model capabilities and develop sufficient confidence so that the model can be used for BMP analyses. This section describes the available data, the calibration/verification process for hydrology and water quality, and the results of this work in modeling the integrated effects of runoff, pollutant generation, and instream processes for flow, sediment, pesticides, and nutrients.

5.1 Four Mile Creek Field Study

The primary site of the data collection efforts associated with the Iowa FEP was the Four Mile Creek watershed located in east-central Iowa. The field program involved comprehensive data gathering, ranging from instrumentation, sampling and analyses of runoff, sediment, pesticides, and nutrients from small field sites and larger watershed areas, to inventories of cropping practices and chemical applications on the entire watershed. The data collection program has been described in detail by Baker et al.,(1979).

Four Mile Creek is located in an intensively farmed agricultural region of Iowa. Primarily row crops are grown in the watershed with 75% to 80% of the current acreage in corn and soybeans. Since nearly all the land is devoted to agriculture, except for roads and farm yards, the remainder of the watershed is comprised of pasture, small grains, and meadow. The surface soils are primarily loess, comprised of silty loam and silty clay loams, that extends up to 10.5 meters in depth along the drainage divides. Natural drainage is well developed in most portions of the watershed, while tile drains have been installed along some waterways and in some fields in the more level upper areas of the basin. The watershed has a generally humid climate typical of Iowa with wide variations in weather conditions. The mean annual precipitation is about 823 mm with a resulting mean annual water yield of 150 mm. The mean minimum January temperature of -11.9 degrees C and the mean maximum July temperature of 30.8 degrees C demonstrate the temperature range experienced in the watershed.

The watershed contains approximately 60 to 70 separate farms in production. Most of the corn cropland is conventionally tilled i.e., plow, disk, and plant, with one-half to one-third of the plowing done in the fall. Soybean land which will be planted with corn in the spring is often disked instead of plowed to incorporate the residue and prepare a seedbed. Most of the farmers apply pesticides to some portion of their cropland, whereas all the farmers apply fertilizer.

Figure 5.1 shows the instrumentation and sampling locations in Four Mile Creek operated as part of the Iowa FEP. Table 5.1 lists the sampling sites where flow measuring devices were installed and/or available. Five recording rain gages were installed at selected sites (generally near flow monitoring sites) within the watershed, with a sixth gage at the weather station near the watershed boundary. From April through October, the monitored weather data included rainfall, daily pan evaporation, daily total wind, max/min air temperatue, relative humidity, and solar radiation. During the winter when the five watershed rain gages were closed, the weather station continued to operate to measure snowfall, max/min air temperatures, soil temperatures, relative humidity, and solar radiation. As part of the data collection program, three small sites (sites #1, #2, and #3) were selected to represent single crop cover conditions under a given set of management practices. Runoff was monitored continuously and samples were taken throughout the hydrograph for analysis of sediment, pesticides, (April through September only) and nutrients. Samples from sites 1 and 2 were analyzed only for sediment and nutrients since pesticides were not applied.

TABLE 5.1 DESCRIPTION OF FLOW-MEASURING STATIONS IN FOUR MILE CREEK

Site No.	Area (ha)	Device	Cover
1	5.6	H Flume	Corn or beans
2	7.6	H Flume	Corn or beans
3	6.0	H Flume	Grass (pastured)
4	5055	USGS Station	Mixed Cover
5	3575	USGS Station	Mixed Cover
6	345	USGS Station	Mixed Cover
7	284	Box Culvert	Mixed Cover
8	149	Headwall and Culvert	Mixed Cover

Soil core samples were taken throughout each growing season and analyzed for pesticides and nutrients; pesticide core samples were concentrated in the period prior to and following application for about two months to establish attenuation and decay characteristics. In addition, chemical applications, crop

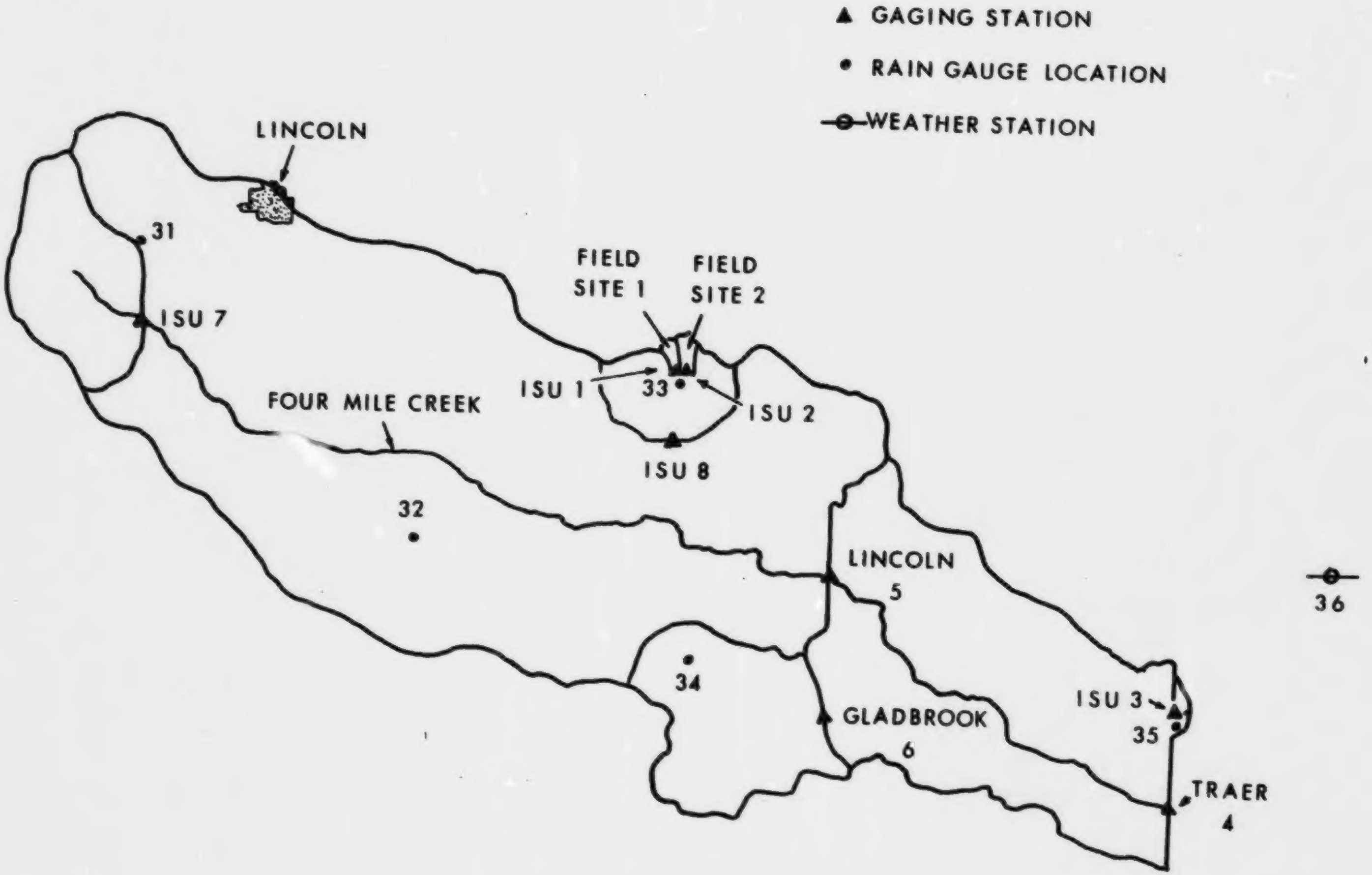

▲ GAGING STATION
• RAIN GAUGE LOCATION
-o-WEATHER STATION
LINCOLN
31
ISU 7
FOUR MILE CREEK
FIELD SITE 1
FIELD SITE 2
ISU 1
33
ISU 2
ISU 8
32
LINCOLN
5
36
34
GLADBROOK
6
ISU 3
35
TRAER
4

Figure 5.1 ISU data collection and sampling locations on Four Mile Creek, IA.

canopy, crop nutrient yields, and nutrient content of rainfall, were sampled and measured, and a log of tillage practices on each site was maintained. At the larger watershed sites (sites #4 #5, and #6), in addition to flow measurements by the USGS, daily grab samples were taken at Site 4 and weekly samples at Sites 5 and 6, with an additional five to ten samples taken during storm events. In addition, tile drainage outlets were sampled and analyzed for nutrients in subsurface flow. All samples were analyzed for sediment and dissolved nutrients (NH_4, NO_3, PO_4, Cl), and selected sediment samples were analyzed for adsorbed NH_4 and available P. From Site 4, samples for pesticide analyses were analyzed for both dissolved and adsorbed forms.

As noted above, inventories of cropping practices and chemical usage in the entire Four Mile Creek watershed were performed.

5.2 Watershed Segmentation and Meteorologic Data Base

One of the basic concepts of watershed modeling using a lumped parameter approach (e.g., HSPF and predecessor models) is the division of the watershed into land segments, each with relatively uniform meteorologic, soils, and land use characteristics. Similarly the channel system is segmented into 'reaches', with each reach demonstrating uniform hydraulic properties. The entire watershed is then represented by specifying the reach network, i.e., the connectivity of the individual reaches, and the area of each land segment that drains into each reach. Each land segment is then modeled to generate runoff and pollutant loads per unit area to the stream channel. Multiplying the unit area runoff and pollutant loads by the area of each land segment tributary to each channel reach determines the runoff and pollutant load to each reach; performing these calculations for each reach in conjunction with modeling the instream hydraulic and water quality processes results in the simulation of the entire watershed.

Figure 5.2 shows the division of the Four Mile Creek watershed into precipitation-derived land segments, i.e., each segment is assumed to receive rainfall from a particular gage, and division of the channel into uniform reaches for this study. We then must superimpose on the precipitation segments the land use/cropping categories in the watershed. For Four Mile Creek we chose the three categories of corn, soybeans, and other/pasture to encompass the range of land uses in the watershed. Due to the relatively uniform character of the predominant soils in the watershed, we assumed no further segmentation due to variations in soil characteristics. Thus, using the four rain gages (ISU stations 31, 33, 34, 35) shown in Figure 5.1 and the three land use categories produces twelve individual land segments (abbreviated PLS in HSPF terminology for 'pervious land segment').

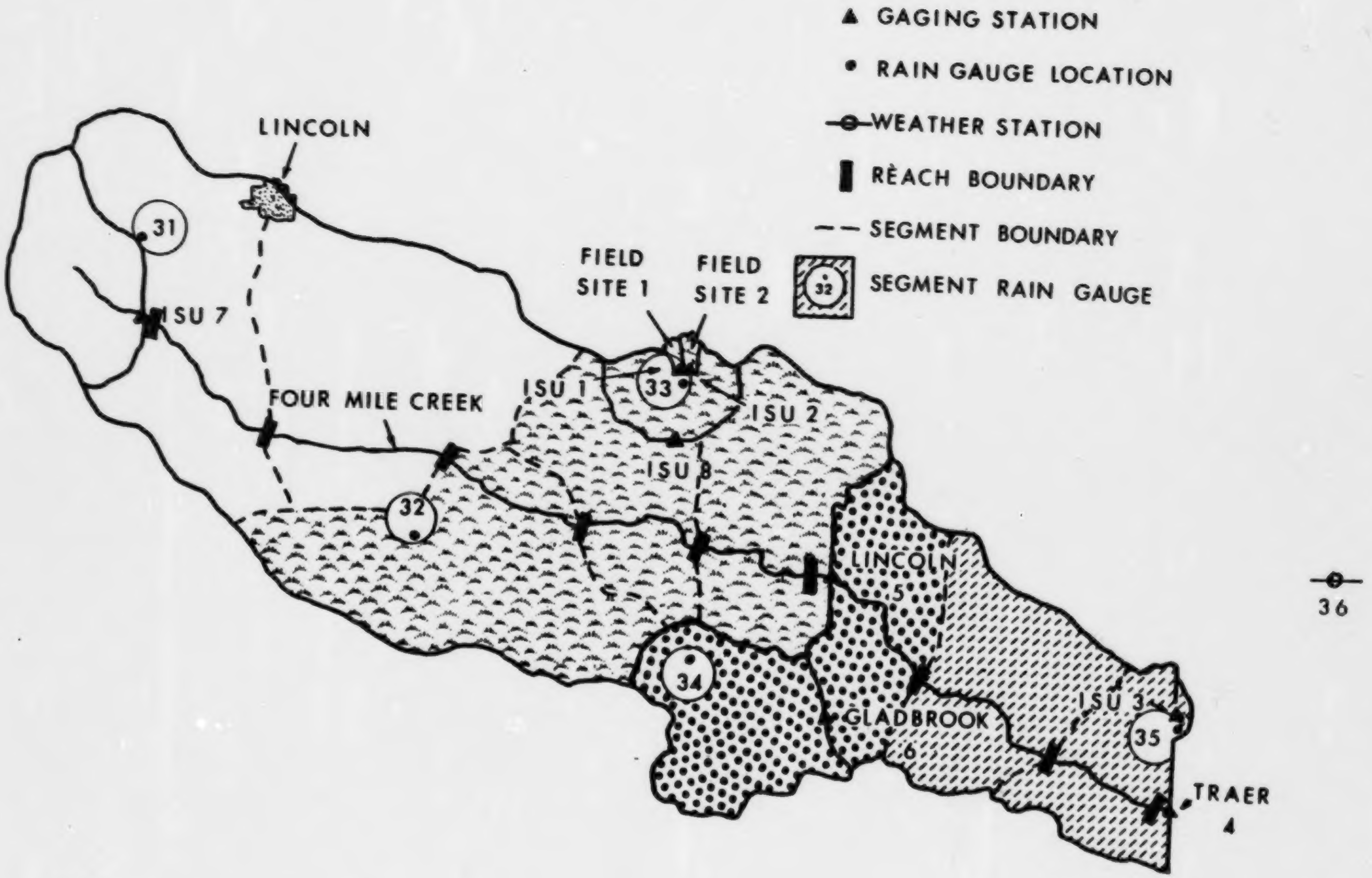

▲ GAGING STATION
• RAIN GAUGE LOCATION
WEATHER STATION
RÈACH BOUNDARY
SEGMENT BOUNDARY
SEGMENT RAIN GAUGE
32
LINCOLN
31
ISU 7
FOUR MILE CREEK
FIELD SITE 1
FIELD SITE 2
33
ISU 1
ISU 2
ISU 8
32
LINCOLN 5
34
GLADBROOK 6
ISU 3
35
TRAER 4
36

Figure 5.2 Watershed Segments and Channel Reach Boundaries on Four Mile Creek, IA.

The segment boundaries for each rain gage shown in Figure 5.2 were made to coincide with the reach area boundaries in order to simplify calculation of segment areas tributary to each channel reach. Originally a Thiessen network was drawn about each of the four precipitation gages (ISU stations 31, 33, 34, and 35); initial simulation runs showed that gage 34 unduly influenced the watershed simulation. Extreme rainfall amounts during selected storms were clearly not representative of the rainfall occurring on the segment. Consequently, the segment area for gage 34 was reduced, and the segment boundaries were adjusted slightly to coincide with the closest reach area boundaries. Table 5.2 lists the primary meteorologic and streamflow data used in the hydrologic calibration and verification of the large watershed sites in Four Mile Creek.

A complete 10-year meteorologic data base from January 1969 to December 1978 was developed with the stations listed in Table 5.2 to perform calibration, verification, and BMP analyses. The last three years of the data base (4/76 - 12/78) were derived from the data collected in the ISU field study; the remainder of the data was obtained from the closest and/or most appropriate nearby weather stations, the locations of which are shown in Figure 5.3.

An inevitable problem that arises when developing a continuous data series is how to fill in missing data points. The 'comments' column in Table 5.2 indicates the assumptions we used to fill in missing data for the various meteorologic information. It is important to be aware of how missing data points are obtained since non-representative data, such as wind movement or air temperature observed at an elevation different than the watershed elevation, can have critical effects on the simulation if the data is not adjusted appropriately. For example, wind data observed with an anemometer at 6.1 meters above the ground must be adjusted downward to expected values at about 0.3 meters elevation for use by HSPF; such an adjustment was needed for the Waterloo wind data listed in Table 5.2.

5.3 Watershed Calibration and Verification

Hydrologic calibration involves iterative adjustments in selected parameter values based on comparison of observed and simulated runoff volumes (annual and monthly values) and storm hydrographs. The model representation and calibrated parameters are then verified by performing the same comparisons on an independent data set, i.e., runoff volumes and hydrographs that were not used in calibration. In Four Mile Creek, observed runoff data for calibration and verification were available for the three watershed sites and the three small field sites. Approximately seven years of daily streamflow data (and selected storm hydrographs) were available for the watershed sites, and 2 1/2

TABLE 5.2 METEOROLOGIC AND STREAMFLOW DATA FOR SIMULATION OF FOUR MILE CREEK, IA.

DATA TYPE	LOCATION	PERIOD OF RECORD	TIME INTERVAL	COMMENT
Precipitation				
Traer	Traer, IA.	1/69-12/78	Hourly	NWS data
ISU Station 31	Four Mile Creek, IA.	4/76-11/78	5-min.	Winter periods missing; filled in from ISU Station 36
ISU Station 33	Four Mile Creek, IA.	4/76-11/78	5-min.	"
ISU Station 34	Four Mile Creek, IA.	5/76-11/78	5-min.	"
ISU Station 35	Four Mile Creek, IA.	4/76-11/78	5-min.	"
Evaporation	Four Mile Creek, IA.	6/76-12/78	Daily	ISU Station 36; Average values used for winter; other gaps filled in with Ames data.
	Ames, IA.	1/69-5/76	Daily	NWS data
Air Temperature	Four Mile Creek, IA.	1/76-12/78	Daily(Max/Min)	ISU Station 36; Missing data filled with NWS Marshalltown data
	Grundy Center, IA.	1/69-12/75	Daily(Max/Min)	NWS data
Solar Radiation	Four Mile Creek, IA.	6/76-12/78	Daily	ISU Station 36; Missing periods filled with Ames data
	Ames, IA.	1/69-5/76	Daily	NWS data through 8/72; 9/72 to 5/76 is from ISU Meteorology Dept.
Wind Movement	Four Mile Creek, IA.	6/76-12/78	Daily	ISU Station 36; Missing periods filled with NWS Waterloo data
	Waterloo, IA.	1/69-5/76	Daily	NWS data
Dewpoint Temperature	Waterloo, IA.	1/69-12/78	Daily	NWS data; Missing data filled in with minimum air temperature
Streamflow				
Four Mile Creek	Traer gage	1/69-9/74; 10/75-12/7	Daily and storm hydrographs	USGS data
	Lincoln gage	10/69-9/74; 6/76-12/78	Daily and storm hydrographs	USGS data
	Gladbrook gage	10/69-9/74; 6/76-12/78	Daily and storm hydrographs	USGS data

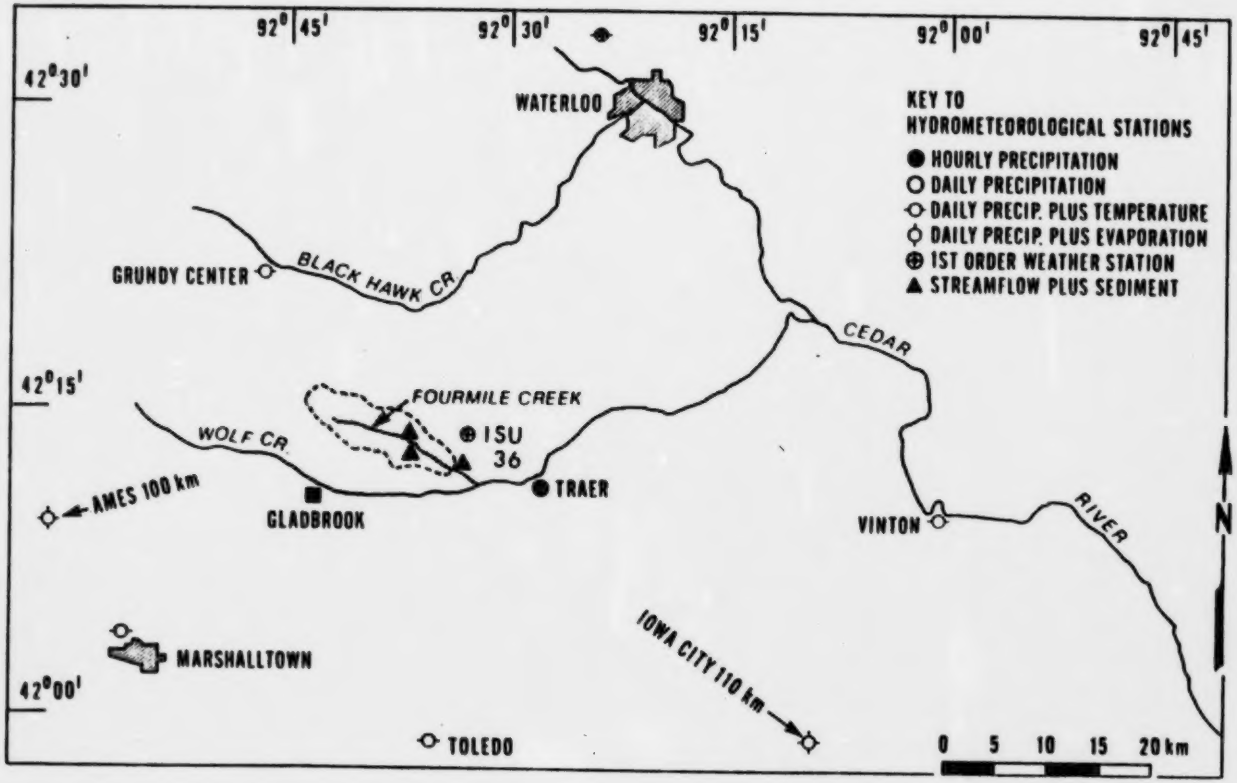

92°|45'
92°|30'
92°|15'
92°|00'
92°|45'
42°30'
42°15'
42°00'
WATERLOO
KEY TO
HYDROMETEOROLOGICAL STATIONS
● HOURLY PRECIPITATION
○ DAILY PRECIPITATION
-○- DAILY PRECIP. PLUS TEMPERATURE
○ DAILY PRECIP. PLUS EVAPORATION
⊕ 1ST ORDER WEATHER STATION
▲ STREAMFLOW PLUS SEDIMENT
GRUNDY CENTER
BLACK HAWK CR.
CEDAR
FOURMILE CREEK
⊕ ISU
36
WOLF CR.
TRAER
AMES 100 km
GLADBROOK
VINTON
RIVER
N
IOWA CITY 110 km
MARSHALLTOWN
TOLEDO
0 5 10 15 20 km

Figure 5.3 Hydrometeorological Stations In and Near Four Mile Creek, IA.

years of runoff data were available from the field sites which experience runoff only during and following storm events.

Both the watershed and field runoff data were used in our hydrologic calibration and verification work; runoff simulation of the field sites allowed us to evaluate relative seasonal changes in specific parameters due to cropping and tillage practices. The seasonal variations were then used in simulating the watershed sites with the assumption that the practices on the field sites are representative of the Four Mile Creek watershed. However, our analyses did show that the calibrated parameter values for infiltration (INFILT), upper zone moisture storage (UZSN), and interflow (INTFW), are significantly different between the watershed and field sites; the relative volume of individual runoff components (i.e., surface, interflow, groundwater) is different at the field and watershed sites, and this affects the resulting calibrated parameter values. The simulation efforts and results for both the watershed and field sites are discussed below with an analysis of runoff modeling problems encountered in Four Mile Creek.

5.4 Watershed Hydrologic Modeling.

Table 5.3 presents a summary of the annual runoff and daily flow statistics for calibration and verification at the Traer gage (Site 4) on Four Mile Creek. The 30-month calibration period extended from April 1976 through September 1978, the period of detailed rainfall monitoring within the watershed; the verification period was from January 1969 to September 1974. The top half of the table includes annual runoff volumes (in millimeters, water-year basis) while the bottom half includes mean daily values (in cms) and flow residuals corresponding to the difference between simulated and recorded daily flows. The columns in Table 5.3 reflect the steps we followed to assess the effect of using rainfall data at different sites for calibration and verification. Because of the short period of detailed rainfall data in Four Mile Creek, the calibration used four rain gages within the watershed while the verification was based on a single rain gage (at Traer, IA) located about 10 kilometers east of the watershed boundary.

Column #1 shows the recorded annual runoff and daily flow statistics for both the calibration and verification periods; note that the stated accuracy of this data can vary by 10% to 15% (or greater) from the actual values. Column #2 shows the results of the final calibration using 12 PLS's (pervious land segments) and 4 rain gages. The calibrated annual runoff is within 10 to 15% of recorded values, and both the mean daily flows (0.186 cms simulated vs. 0.172 cms observed) and peak daily flows (4.98 cms simulated vs. 5.72 observed) are closely simulated. The mean

TABLE 5.3 FLOW CALIBRATION AND VERIFICATION RESULTS FOR THE TRAER GAGE, FOUR MILE CREEK, IA.

COLUMN:	RECORDED (1)		FINAL CALIBRATION (2)	RUNS WITH TRAER GAGE RAINFALL (3)	(4)	VERIF. RUN (WITH TRAER RAINFALL) (5)
CONDITIONS:	Accuracy-95% of flows are within 10% except in the winter when records are poor (Errors > 15%)		12 Pervious land segmts 4 Rain gages	12 Pervious land segmts. 1 Rain gage	3 Pervious land segmts. 1 Rain gage	3 Pervious land segmts. 1 Rain gage
ANNUAL RUNOFF (mm)						
4/76-9/76	76.2		68.6	80.0	87.1	
10/76-9/77	11.4		15.7	24.6	24.4	
10/77-9/78	182.0		205.0	287.0	287.8	
TOTAL	269.6		289.3	391.7	399.3	
1/69-9/69	395.0					334.8
10/69-9/70	144.0					159.8
10/70-9/71	287.0					224.8
10/71-9/72	198.0					234.4
10/72-9/73	458.0					307.1
10/73-9/74	288.8					259.6
TOTAL	1771.0					1520.4
DAILY FLOW STATISTICS (cms)	CALIB. PERIOD	VERIF. PERIOD				
MEAN	0.172	0.4933	0.186	0.252	0.252*	0.4247
STD.DEV.	0.376	1.011	0.348	0.530	0.537*	0.9115
MAX.	5.27	12.0	4.98	7.90	8.04	14.5
MIN.	0	0.0057	0	0	0	0
DAILY FLOW RESIDUALS (SIM.-REC.,cms)						
MEAN			0.013	0.079	0.0889*	-0.0685
STD.DEV.			0.3004	0.4202	0.4347*	1.069
MAX.			4.87	7.53	7.67	13.6
MIN.			-2.97	-1.9	-2.04	-10.5

* - This run was for 10/75 to 9/78 in order to evaluate the simulation during an additional winter period. The resulting flow and residual statistics are based on this 3-year period.

flow residual corresponds to the difference between the simulated and recorded mean flows (i.e., 0.186 - 0.172 = 0.014), whereas the standard deviation, maximum, and minimum residuals reflect differences in timing of the daily flows. The values in Table 5.3 are derived entirely from the HSPF PERLND simulation without the effects of instream hydraulic routing and associated changes in hydrograph timing and peak flow attenuation. Subsequent calibration of storm hydrographs (not shown here) with instream routing and adjustments of roughness coefficients and interflow parameters resulted in improved timing of simulated and observed hydrographs.

Column #3 shows the result of using the Traer rainfall record outside the watershed, in place of the four ISU gages. Although the annual rainfall at Traer for the calibration period was less than 10% greater than the Four Mile Creek watershed average, the total runoff (391.7 in.) and mean daily flow (0.252 cms) were 35% greater than the values simulated with the ISU rainfall data. These differences demonstrate the effects of rainfall variations in determining runoff.

Computer costs are an important consideration in any modeling project of this magnitude. Costs increase more than linearly as the number of PLS's increase, i.e., simulating 5 PLS's will cost more than 5 times the cost of one PLS. Thus to reduce run costs, we then used average slope and overland flow length values (Column #4) to reduce the number of PLS's from 12 to 3; these two parameters were the only differences among the PLS's in a single land use category retained from the final calibration (Column #2). Comparing Columns #3 and #4 shows that this change had an insignificant effect on the overall simulation; however, impacts on individual storms would be more significant. Thus Column #4 indicates the effects of errors in the simulation introduced primarily by using the Traer rainfall and 3 PLS's.

The results of the verification run in Column #5 show that the annual runoff volumes are generally within 10 to 20% of the observed volumes, except for the 1973 water year which accounts for more than 60% of the difference in the total runoff volumes for the verification period. The mean simulated flow of 0.425 cms agrees well with the observed value of 0.4933 cms, and the difference (0.0685 cms) represents only 14% of the observed mean flow. These differences fall well within the errors associated with the use of the Traer rainfall, as reflected in the absolute value of the mean residual (0.0889 cms, in Column #4), and its percentage of the observed mean flow (18%). Consequently, this demonstrates that the hydrologic calibration at Four Mile Creek is verified.

The fact that the calibration results are somewhat greater than the observed values while the verification results are somewhat less than observed is likely due to two reasons. The calibration period included drought conditions during 1976-77, and 'no flow' conditions occurred on numerous days for the first time since gaging began in 1962.

Consequently, the calibrated parameters are slightly biased toward low and moderate flow conditions. Also, it was discovered that the radiation time series used during the verification was in error, with values 50% less than the observed radiation measurements. Correcting this error would increase runoff due to snowmelt with an associated increase in the mean simulated flow. Thus, the verification results and agreement with observed values shown in Table 5.3 would be improved.

Another way to examine flow modeling results is to compare simulated and observed flow frequency information as shown in Figure 5.4. For the calibration period, the agreement is good to excellent in the moderate flow range of 0.23 to 4.25 cms. The frequency results using the Traer rainfall during the calibration period (dashed line) are consistently higher than observed. Studies by Baker et al., (1979) have noted the variations in rainfall intensity in the Four Mile Creek area, and Leytham and Johanson (1979) concluded that although the general climatic regime is similar, the storm rainfall distribution and intensity at Traer does not accurately represent conditions on the watershed. In spite of this, and in light of the drought conditions and radiation data error noted above, the frequency results for the verification period confirm our assessment that the flow calibration is verified.

Figure 5.5 shows and compares the daily flow simulation results for the 1978 water year using both the ISU and NWS Traer rainfall data. Although the verification results discussed above confirm that the calibration is verified, this does not mean that each and every storm event is accurately reproduced. The results in Figure 5.5 demonstrate the following problems and considerations that need to be discussed especially when the flow simulation is subsequently used to model water quality of specific storm events;

a. The use of the Traer rainfall results in pronounced differences between the simulated values in the two graphs, which are especially critical in a water quality sense during summer thunderstorm periods. Thus, the storm of June 28 was simulated as a major event with the Traer rainfall and a minor peak in the hydrograph with the ISU data. Also, the events of May 27 and May 31 on the watershed were not even simulated with the Traer rainfall. Since these occurred during and immediately following the period of herbicide application, the impact on water quality would likely be significant.

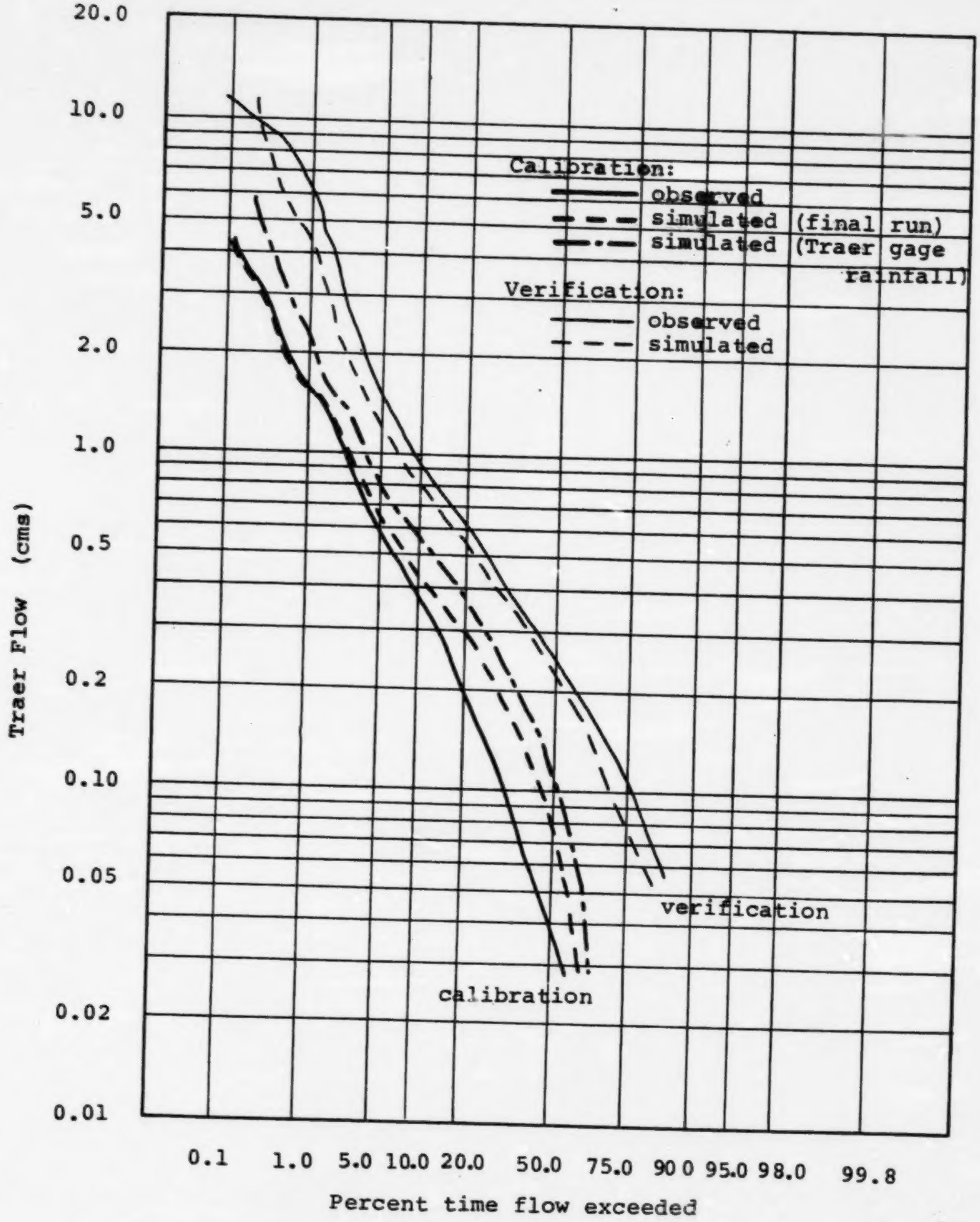


Figure 5.4 Flow frequency results for the calibration and verification periods on Four Mile Creek, IA.

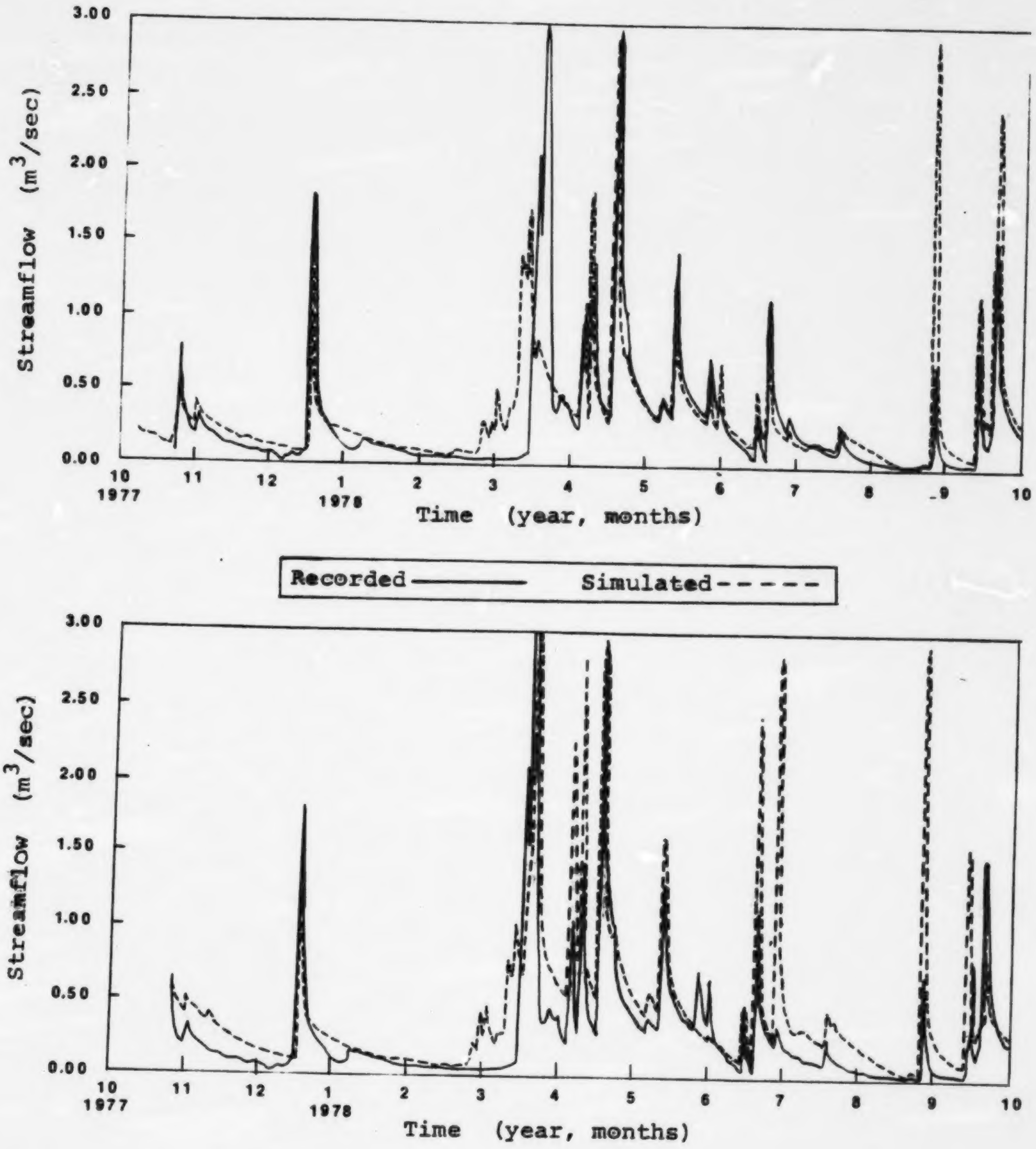


Figure 5.5 Comparison of daily flow simulation on Four Mile Creek using ISU Rainfall (top graph) and NWS Rainfall at Traer, IA. (bottom graph).

b. The timing of snowmelt in March is not well represented. This is due to both the use of meteorologic data series (e.g., radiation, wind, temperature) with numerous gaps that were filled in with data from other stations, and the inability of the model to accurately represent frozen ground conditions. Also, only one snowmelt period (March 1978) was included in our calibration period since no significant melt occurred in 1977. Based on the simulation of the field sites (discussed below), the INFILT and UZSN parameters were reduced during the winter months, and the snow input (SNOWCF parameter) was increased, in order to match the volume of surface runoff that was measured. Additional research and model development work is needed to better understand and represent frozen ground conditions and the timing and volume of snowmelt runoff.

c. The existence of tile drainage in the watershed, and increasing installation of tile drains over the calibration and verification periods, has a definite impact on the watershed hydrology that is not directly represented by HSPF. The tile drains in the watershed are located primarily about 90 - 150 cm deep along many of the gullies and drainage channels in the watershed; their exact location and extent is unknown. Except during extreme droughts (such as in '76-77) the tiles flow continuously indicating that some portion of the tile line is below the saturated water surface in the soil profile. HSPF has no mechanism to deplete the lower soil zone (where the tiles are actually located) except by evapotranspiration. The tiles affect infiltration, by lowering the soil moisture, and the recession of the hydrograph. Our final parameter set was calibrated to simulate the outflow hydrograph, and thus includes the effects of the tile drains, as shown by the generally good representation of hydrograph shape and recession in Figure 5.5 (top graph). The existence of fewer tile drains during the verification period would result in a lower infiltration rate which is consistent with the simulation results presented above.

d. As shown in Figure 5.5, late summer events are consistently over-simulated. This occurred frequently both in the calibration and verification periods, and in previous modeling work by Leytham and Johanson (1979) on Four Mile Creek. The cause is unclear but may be due to highly variable thunderstorm rainfall, and increased infiltration through deep cracks that develop after extended dry periods. Further investigation is needed.

Field Sites vs. Watershed Sites Our initial approach in the hydrology calibration was to use the detailed rainfall and runoff data from the small field sites (ISU #1, #2, and #3) to develop a set of calibrated hydrology parameters for each land cover condition, and then use these parameter sets for the corresponding crop segments on the entire watershed. The only changes necessary would be related to the volume and timing of subsurface flow which was not present on the field sites, and to the physical characteristics (e.g., slope, overland flow length) of the entire watershed.

After numerous simulation trials on both the field sites and the entire watershed, we have concluded that the same parameter values for UZSN, INFILT, and INTFW cannot be used to adequately simulate the hydrology at both levels. The field sites generally required INFILT (infiltration parameter) values three to four times larger than the watershed sites, and UZSN values considerably smaller, primarily for the row crop field sites, in order to generate the runoff volumes observed during the high intensity summer storms. Similar parameter adjustments were noted by Onishi et al., (1979) in a preliminary application of the ARM model to ISU Sites #1 and #7. Also, the same high infiltration rates and low UZSN values were calibrated by Donigian et al., (1977) in ARM model testing on small watersheds less than 4 hectares in Georgia and Michigan. The evidence indicates that such a mix of INFILT and UZSN values is needed to model small watersheds less than 8 to 20 hectares especially in thunderstorm-prone areas, but that parameter adjustments are required to adequately simulate a larger surrounding watershed. Our simulation runs for the Gladbrook watershed (ISU #6) which is intermediate in size (344 hectares) between the field and larger watershed sites confirmed that it would best be simulated by some intermediate values for UZSN and INFILT.

Our calibration efforts on the small field sites, although not producing a parameter set for the watershed, did allow us to develop a relative range of parameter values for the primary crops/land use categories in the watershed, and to investigate and better calibrate snowmelt runoff as affected by frozen ground conditions. Table 5.4 compares the field site and watershed values for parameters that were adjusted by calibration.

Cropping and primary tillage practices were alternated between field Sites #1 and #2 during the 1976-78 calibration period as follows:

	Site 1		Site 2	
	Primary Tillage	Crop	Primary Tillage	Crop
1976	Plowing (moldboard)	Soybeans	Disking	Corn
1977	Disking	Corn	Plowing (moldboard)	Soybeans
1978	Plowing (moldboard)	Soybeans	Disking	Corn

The practice of rotating crops and associated tillage practices, chemical applications, etc. presents difficult operational problems for continuous simulation models, since the land surface characteristics and chemical loadings change drastically during the year and during the same period in different years of the calibration period. To partially circumvent these problems, we considered ISU Site #1 and Site #2 to be identical (paired) watersheds since they have similar soils and topographic characteristics. Therefore we simulated two pervious land segments (PLS): PLS 1, with plowing as primary tillage followed by soybeans and associated practices, and PLS 2, with disking as primary tillage followed by corn and associated practices.

This approach allowed us to concentrate on the effects of cropping and tillage practices by simulating the PLS for the entire 1976-78 period and comparing the simulated values to the 'appropriate' observed data. For example, the PLS 1 values were compared to the 1976 and 1978 data on Site #1 and the 1977 data on Site #2, i.e., the plowing/soybeans practice combination. In spite of our efforts, a uniform set of values for UZSN and INFILT could not be developed to adequately model runoff from the row crop field sites for the entire calibration period, primarily due to the dominant and time-varying effects of tillage operations on infiltration and surface moisture detention.

The effects of tillage operations cause numerous problems for calibration. The effect of a tillage operation on a particular storm event depends on its extent (depth) and severity, and the time elapsed between the tillage operation and the storm. Also, the second and third storm after a tillage operation will be impacted less than the first storm. HSPF allows us to partially account for these effects with the use of monthly values for UZSN and the ability to change parameter values (such as INFILT) during the simulation. But with the short period of record available for calibration the end result is calibrating a particular parameter value (e.g., INFILT for plowing or disking)

TABLE 5.4 VALUES OF SELECTED HSPF HYDROLOGY PARAMETERS USED FOR THE FIELD SITE AND WATERSHED SITE SIMULATIONS

	PLS #1 (Beans/Plowing)		PLS #2 (Corn/Disking)		PLS #3 (Other/Pasture)	
	FIELD	WATERSHED	FIELD	WATERSHED	FIELD	WATERSHED
UZSN:						
Jan	2.5	7.6	2.5	7.6	20.	20.
Feb	2.5	7.6	2.5	7.6	20.	20.
Mar	2.5	7.6	2.5	7.6	20.	20.
Apr	13./10.	18.	10./7.6	15.	23.	25.
May	21./20.	28.	13./11.	23.	25.	28.
Jun	8.9/5.1	18.	4.6/4.6	15.	25.	30.
Jul	3.8/2.5	18.	4.6/13.	15.	28.	30.
Aug	015.	23.	13.	23.	28.	30.
Sep	15.	23.	13.	23.	28.	30.
Oct	13.	23.	15.	23.	28.	30.
Nov	13.	15.	15.	15.	25.	25.
Dec	13.	13.	13.	13.	23.	20.
INFILT:						
Base	7.1	2.3	7.1	2.3	12.	3.5
Plow	13.	3.0	-	-	-	-
Disk	9.1	2.5	7.6/8.1	2.8/2.5	-	-
Cultiv.	9.1	2.5	8.6/9.1	2.8/2.5	-	-
Frozen ground	.81	1.5	.81	1.5	1.0	2.0
INTFW:	.6	1.0	.6	1.0	.8	1.2
IRC:	1.0E-30	.6	1.0E-30	.6	1.0E-30	.8
LZSN:	203.	216.	203.	216.	229.	241.
SNOWCF:	1.5	1.45	1.5	1.45	1.5	1.45

Units are millimeters for UZSN and LZSN, and millimeters/hour for INFILT

UZSN values for the field sites of PLS 1 and PLS 2 for April through July were different for the 1978 and 1976 simulation periods; format is : 1978 UZSN/1976 UZSN.

on one or two storm events. The only way to avoid this is to use a longer calibration period with many events used to calibrate a particular parameter.

Consequently, the specific parameter values in Table 5.4 are based on few data points, but they are informative in terms of the relative differences between practices. The dual values for UZSN for the April through July period were necessary to reasonably model the surface runoff from Sites #1 and #2 as a basis for the pesticide calibration and verification periods of 1978 and 1976, respectively; simulation of the field sites for runoff, sediment, and pesticides will be discussed in the 'water quality' section. Differences in timing between tillage operations and storm events in 1976 and 1978 required changes, primarily to UZSN, to represent the surface runoff during the two summer periods. Since no tillage occurred on the pasture sites, the single set of values for UZSN worked reasonably well for the entire period.

In general, UZSN values were higher during April and May due to tillage, and lower in June and July from seedbed preparation and compaction. Higher UZSN values for the remainder of the summer were needed to match the observed runoff; they can be possibly attributed to increased surface depression and retention. However, simulation of late summer storms is a problem discussed previously.

To model the observed snowmelt runoff, it was necessary to decrease both UZSN and INFILT values during the winter months. These adjustments are logical in terms of frozen soil being less capable of retaining moisture and allowing infiltration, and they forced the hydrologic model to generate the observed volumes of surface runoff. On the field sites, infiltration was decreased by a factor of 5 to 10, as shown in Table 5.4. Also, the factor for increasing snowfall (SNOWCF) due to areal variability and measurement inaccuracies was calibrated.

Although HSPF PERLND simulates all flow components, only the surface runoff component was compared to observed values assuming little or no interflow occurs from the small field sites. The interflow parameters were adjusted, however, so that the interflow volume was an assumed small fraction of the surface runoff. Since interflow occurs only during and immediately following storm events for small areas, the interflow recession parameter (IRC) was set essentially to zero (1.0 E-30 in Table 5.4, since a value of 0.0 is read as a blank space by the program) so that the interflow would end soon after the event. For the watershed sites, interflow can extend for a few days or more requiring a higher value for IRC.

The experience in calibrating on the small field sites was then used to develop the parameter sets for the PLS's used in the watershed simulation. Although the actual parameter values are different, the same relative changes for tillage operations and snowmelt runoff shown in Table 5.4 were used to successfully calibrate and verify the watershed hydrology simulation.

5.5 Field Site Water Quality Simulation

Since the hydrology parameters for the field and watershed sites were considerably different, the goal of the field site water quality simulation was to calibrate and verify the sediment and pesticide parameters, to the extent possible using the field site hydrologic parameters. The same water quality parameter values were then used with the watershed hydrology parameters to see if the field site sediment and pesticide parameters could be extrapolated to the watershed level for a reasonable simulation of sediment and pesticides at the watershed outlet. On field Sites #1 and #2, five storm events in 1978 were the primary basis for calibration and two storm events in 1976 were used for verification. Using alternate years allowed us to circumvent the problems of crop and practice rotations discussed above; in both 1976 and 1978, Site #1 was planted with soybeans after plowing as primary tillage, and Site #2 was planted with corn after disking in the spring. Moreover, 1977 was a drought year with few observed pesticide runoff samples.

Calibration procedures used were essentially identical to those discussed by Donigian and Davis (1978) for the ARM model, with the primary emphasis on simulation of total storm event runoff and losses of sediment and pesticides. Peak flows, sediment concentrations, and pesticide concentrations during storm events were checked for consistency between the simulated and observed values; however, project resources did not allow for detailed comparison of flow and concentrations during storm events.

Since the sediment and pesticide simulations were performed for the summer periods of 1976 and 1978, the monthly UZSN values for April through July were adjusted (as noted above) to improve the runoff simulation during these summer periods when pesticide runoff was greatest. Also, the sediment erosion calibration was not emphasized because the pesticides simulated were transported primarily in soluble form, and without analysis of erosion during storm events the existence of transport versus sediment limiting conditions needed for calibration cannot be determined. The goal was to obtain a reasonable simulation of monthly and storm volumes of runoff and sediment to provide a valid basis for the pesticide calibration and verification.

The steps in the pesticide calibration process were as follows:

a. Estimate all pesticide and solute leaching parameters from the literature and all available information on the field site;

b. Adjust pesticide decay rates (primarily in surface and upper soil zones) to better reflect the observed soil core data;

c. Adjust solute leaching parameters (primarily surface and upper zone values) to better reflect the pesticide distribution between the surface and upper zones, as determined from the soil core data or calibration with a nonreactive tracer (e.g., chloride);

d. Adjust adsorption/desorption parameters as needed to obtain the proper distribution between solution and adsorbed forms;

e. Compare storm event pesticide losses in solution and adsorbed forms with observed data and make further parameter adjustments as discussed in b, c, and d above.

The final pesticide and solute leaching parameters are listed in Table 5.5. The pesticide decay parameters were initially determined from soil core data on the field sites, and subsequently adjusted through calibration.

Adsorption parameters were obtained from the literature (Baker et al., 1978; Baker and Johnson, 1979) with only minor adjustments through calibration, and solute leaching parameters were calibrated on the available chloride soil core data. Extensive scatter in the observed soil core pesticide and chloride data resulted in a range of decay rates and leaching parameters which was subsequently reduced through the calibration process to the final values shown in Table 5.5.

Figures 5.6 and 5.7 show sample calibration and verification results for alachlor and paraquat soil storages on ISU Sites #1 and #2, respectively. The multiple lines in each graph show the total pesticide storage, surface storage, and upper zone storage. For alachlor (Figure 5.6), the relative positions of the surface and upper zone graphs reflect the leaching of the surface pesticide to the upper zone. Within 10 days following application, the majority of the alachlor has either decayed or moved from the narrow surface layer (0.635 cm) to the upper soil zone (14.5 cm).

TABLE 5.5 PESTICIDE AND SOLUTE LEACHING PARAMETERS FOR ALACHLOR, CYANAZINE, AND PARAQUAT

	ALACHLOR	CYANAZINE	PARAQUAT
DECAY RATES (per day):			
Surface Zone [a]	0.12/0.06	0.06	0.01/0.007
Upper Zone	0.045	0.04	0.003
ADSORPTION PARAMETERS:			
CMAX (ppm)	242.	171.	5000.
XFIX (ppm)	0.0	0.0	500.
K1:			
Surface zone	4.0	4.0	200.
Upper zone	4.0	3.0	200.
N1	1.4	1.25	2.0
SOLUTE LEACHING PARAMETERS:			
Surface (SLMPF)	0.7	0.7	0.7
Upper Zone (ULPF)	5.0	5.0	5.0

a. For alachlor and paraquat, initial decay rates were reduced to the second value ten days after application.

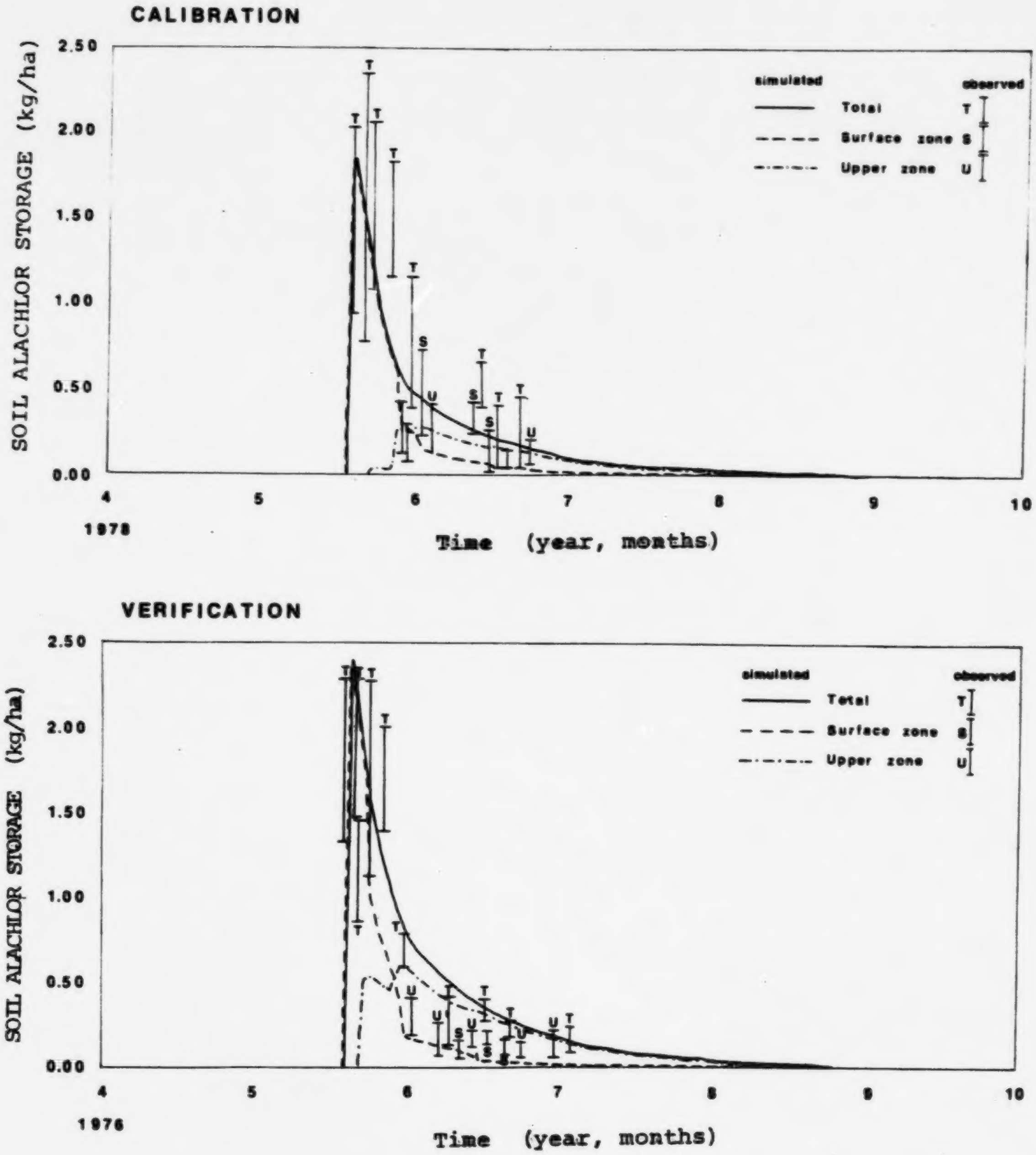


Figure 5.6 Calibration and Verification results for soil alachlor storages on PLS #1 (soybeans).

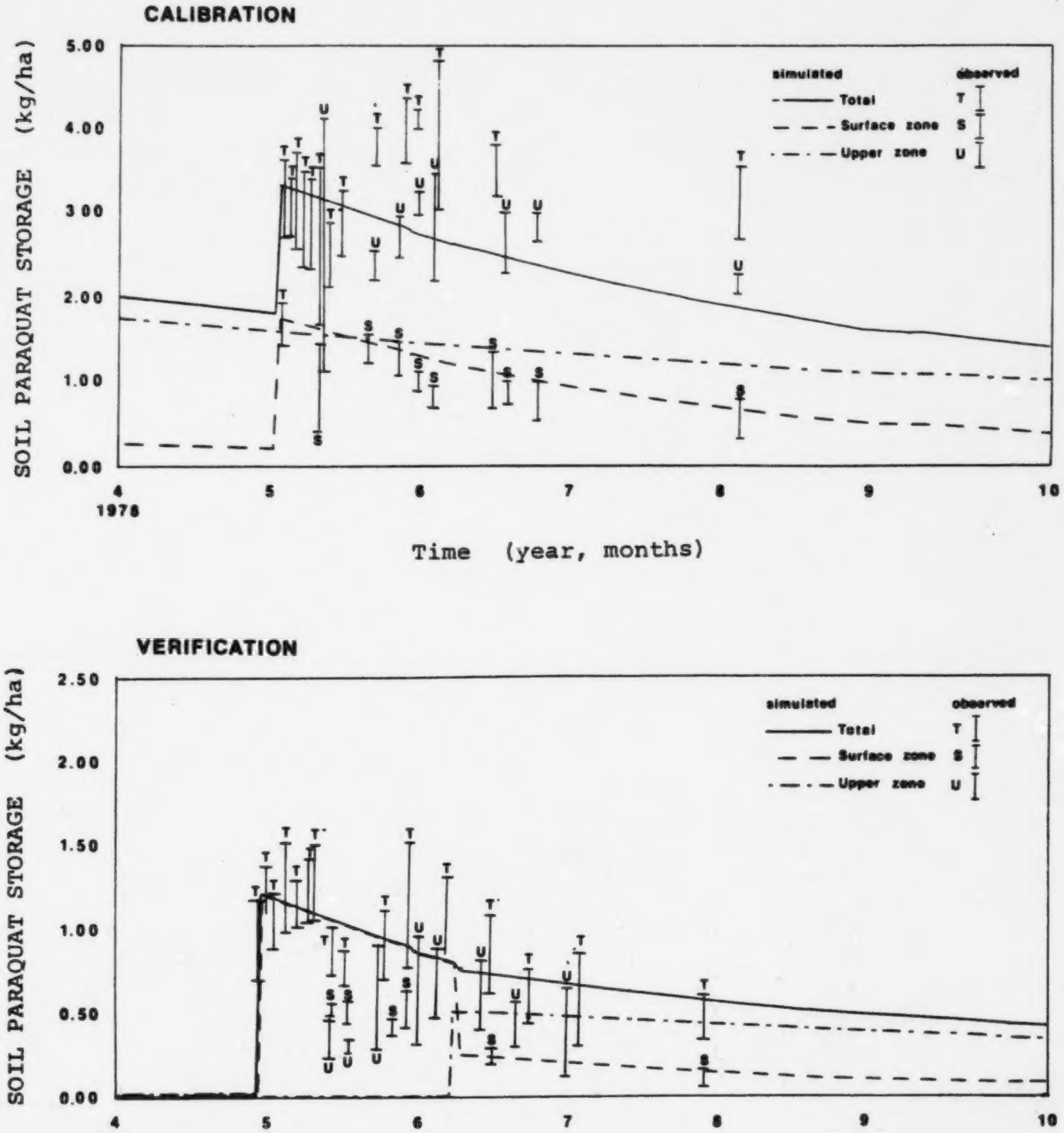


FIgure 5.7 Calibration and Verification results for soil paraquat storages on PLS # 2 (corn).

Paraquat (Figure 5.7), with its slow decay and strong adsorption to soil particles, essentially remains in the surface layer except for redistribution by tillage practices as shown by the abrupt change in the graphs on June 7, 1976 due to field cultivation. Paraquat accumulated in the soil over the three year period so that 1.6 kg/ha was present in the soil prior to the 1978 growing season, whereas none existed prior to 1976.

Both alachlor and paraquat demonstrated higher decay rates for about 2 weeks following application than later in the summer; for alachlor the effect was greater in 1976 than 1978. Thus higher rates were used for the surface zone for 10 days following application, as noted in Table 5.5. This effect was not evident for cyanazine.

Considering the scatter in the observed pesticide soil data, the simulation provides a reasonable representation of pesticide during both the calibration and verification periods. The standard deviation limits shown about the observed data reflect uncertainties in sampling procedures and natural spacial variability; they demonstrate the inherent difficulties in estimating the amount of pesticide present in the soil. This uncertainty also exists in determining the pesticide application amounts that actually reach the soil surface. This scatter is especially notable for paraquat where the estimated soil storages can be significantly greater than the sum of initial values and application amounts, as shown in Figure 5.7. The distribution between the surface and upper zones is also uncertain since the 'observed' surface storages were prorated as a fraction of the 0-1 cm sampling depth. Considering all these possible sources of discrepancies, the overall model representation is quite acceptable.

Tables 5.6, and 5.7 show the results of the pesticide runoff calibration and verification on Sites #1 and #2, respectively, along with the associated surface runoff and sediment results. April and May storm totals, and monthly totals for April through September are included. Values of surface runoff (SURO) and the total of surface runoff plus interflow (PERO) are presented; the sediment and pesticide simulated losses are for surface runoff only, but the values of SURO and PERO often bracket the observed runoff values. The results in these tables indicate the following:

a. Differences in the simulated and observed pesticide losses are exaggerated reflections of inaccuracies in the runoff and sediment simulation. When runoff is over-simulated soluble pesticide fractions are generally over-simulated, and the paraquat simulation closely reflects the sediment simulation.

TABLE 5.6 SIMULATION RESULTS FOR ISU FIELD SITE #1

	SURFACE RUNOFF (mm)			SEDIMENT(tonne/ha)		--------------- ALACHLOR (kg/ha)					-----------------	PARAQUAT (kg/ha)	
	Observed	Simulated		Observed	Simulated	Observed			Simulated			Observed	Simulated
CALIBRATION		SURO	PERO			WAL	SAL	TOTAL	WAL	SAL	TOTAL	SPA	SPA
April	1.42	1.88	3.61	.090	.105	0	0	0	0	0	0	0	0
5/27/78	1.19	1.68	2.03	.364	.256	.00290	.00016	.00306	.01858	.00101	.01959	.00354	.00470
5/15/78	0.23	0.33	0.53	.048	.012	.00045	.00001	.00046	.00170	0	.00168	.00039	.00022
May	1.55	2.03	2.72	.417	.269	.00336	.00017	.00353	.02026	.00101	.02127	.00393	.00493
6/15/78	0.86	0.86	1.22	.098	.043	.00336	.00001	.00035	.00067	0	.00067	.00097	.00067
6/20/78	3.51	2.84	3.84	.326	.201	.00112	.00002	.00114	.00101	.00011	.00112	.00289	.00291
June	4.39	3.81	5.28	.424	.246	.00157	.00003	.00160	.00201	.00011	.00213	.00386	.00358
July	0	0.05	0.08	0	0	0	0	0	0	0	0	0	0
August	0.08	3.81	3.81	0	.602	0	0	0	0	0	0	0	.00437
September	0.56	0.46	0.74	.012	.007	0	0	0	0	0	0	0	0
TOTAL	8.00	12.04	16.24	.943	1.229	.00493	.00020	.00513	.02228	.00112	.02340	.00779	.01299
VERIFICATION													
April	0.74	0.43	1.45	.040	.007	0	0	0	0	0	0	0	0
5/29/76	3.89	7.21	8.08	2.044	2.571	.00616	0	.00616	.04254	.00627	.04881	.01245	.05060
May	3.89	7.24	8.13	2.044	2.571	.00616	0	.00616	.04321	.00627	.04881	.01245	.05060
6/13/76	8.23	6.53	8.20	.854	.728	.00526	.00013	.00540	.00448	.00034	.00481	.00702	.01153
June	8.23	6.63	8.38	.854	.731	.00526	.00013	.00540	.00459	.00034	.00493	.00702	.01153
July	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	12.86	14.30	17.96	2.938	3.309	.01142	.00013	.01155	.04780	.00660	.05373	.01947	.06213

a. - Monthly UZSN values were adjusted to better simulate runoff
b. - SURO is surface runoff only, while PERO includes surface and interflow
c. - Simulated pesticide values were limited to an accuracy of 0.0001 lb/ac = 0.09 gm/ha
WAL - Solution alachlor
SAL - Sediment alachlor
SPA - Sediment paraquat

TABLE 5.7 SIMULATION RESULTS FOR ISU FIELD SITE #2

	SURFACE RUNOFF (mm)			SEDIMENT(tonne/ha)		CYANAZINE (kg/ha)						PARAQUAT (kg/ha)	
	Observed	Simulated		Observed	Simulated	Observed			Simulated			Observed	Simulated
CALIBRATION		SURO	PERO			WCY	SCY	TOTAL	WCY	SCY	TOTAL	SPA	SPA
April	6.27	6.99	10.46	.173	.278	0	0	0	0	0	0	0	.00101
5/13/78	0.05	0.38	1.09	0	.004	.00011	0	.00011	.00437	0	.00437	.00002	.00011
5/27/78	10.24	7.49	8.59	1.841	1.595	.01534	.00279	.01812	.01187	.00146	.01332	.03991	.03403
5/29/78	0.74	1.24	1.70	.141	.072	.00134	.00022	.00157	.00101	0	.00101	.00242	.00146
May	11.03	9.11	11.43	1.982	1.671	.01679	.00301	.01980	.01769	.00146	.01914	.04235	.03548
6/15/78	2.41	1.78	2.21	.159	.128	.00101	.00010	.00111	.00034	0	.00034	.00263	.00213
6/20/78	1.85	3.02	4.04	.096	.173	.00101	.00008	.00109	.00022	0	.00022	.00162	.00280
June	4.26	4.80	6.60	.256	.305	.00190	.00018	.00208	.00067	0	.00067	.00425	.00504
July	0	0.05	0.05	0	0	0	0	0	0	0	0	0	0
August	0	5.16	5.16	0	.736	0	0	0	0	0	0	0	.00593
September	0.10	0.33	0.51	.004	.004	0	0	0	0	0	0	0	0
TOTAL	21.66	26.44	34.24	2.415	2.994	.01869	.00319	.02188	.01836	.00146	.01981	.04660	.04746
VERIFICATION													
April	7.95	4.67	7.59	.693	.298	0	0	0	0	0	0	0	0
5/29/76	11.38	10.34	11.25	3.990	2.485	.01690	.00195	.01885	.01243	.00179	.01422	.06855	.03481
May	11.38	10.36	11.33	3.990	2.485	.01690	.00195	.01885	.01299	.00179	.01478	.06855	.03481
6/13/76	1.19	3.20	3.91	.052	.191	.00044	.00002	.00046	.00056	0	.00056	.00024	.00067
June	1.19	3.23	3.96	.052	.191	.00044	.00002	.00046	.00056	0	.00056	.00024	.00067
July	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	20.52	18.26	22.88	4.735	2.974	.01734	.00197	.01931	.01354	.00179	.01534	.06879	.03548

WCY - Solution cyanazine
SCY - Sediment cyanazine
SPA - Sediment paraquat

b. The sediment fractions of the soluble pesticides, especially alachlor, show greater deviations than the soluble fractions. This indicates that further adjustments in the adsorption parameters could improve the simulation.

c. Although sediment calibration was not emphasized in this work, sediment losses are generally simulated as well as the runoff volumes during both the calibration and verification periods.

d. For Site #1, alachlor monthly and storm losses are simulated 4 to 5 times higher than observed with the largest differences in May, the month following application; corresponding paraquat values for the verification period are 2 to 4 times higher than observed. Sediment alachlor deviations are even greater, but represent less than 5% of total alachlor loss. For alachlor, the calibration and verification results are similar indicating that additional calibration would improve the verification results. For paraquat, the calibration results are considerably better with deviations in the range of only 30% to 40%. The over-simulation of runoff and sediment during both the calibration and verification appears to be the major cause for pesticide over-simulation.

e. Pesticide simulation results for Site #2 are considerably better than noted above for Site #1, with much of the credit due to improved runoff and sediment simulation. Cyanazine monthly and storm losses are simulated only 20% to 40% less than observed values, except for June 1978. Both the calibration and verification period show this close agreement. The paraquat calibration also shows deviations in the range of 10% to 40% from observed values, but the verification is based on a very small and very large event with significant differences in the sediment simulation. Consequently, we feel the verification results for paraquat are not indicative of the calibration since improvements in the sediment simulation would significantly improve the paraquat verification results.

In summary, the simulation results for the field sites are somewhat mixed, with the Site #2 calibration and verification results significantly better than those for Site #1. This could be partially due to the differing tillage practices. However, the discrepancies are consistent and promising, in that improved runoff and sediment simulation would definitely improve the pesticide simulation. Moreover, the pesticide parameter values are well within the range of values noted in the literature. Thus, we feel the overall field site calibration and verification results are adequate and sufficient to justify use of the sediment and pesticide parameters in the watershed simulation.

5.6 Instream Simulation of Sediment

Simulation of instream sediment transport processes (i.e., advection, deposition, scour) was performed using HSPF module section SEDTRN. The model considers inflow of sediment from upstream reaches, loadings from contiguous land segments, exchange of sediments between the bed and suspension, and outflow to downstream reaches. Since both the migration characteristics and the adsorptive capacities of sediment vary significantly with particle size, the three components of sediment (sand, silt, and clay) are simulated individually, and hence initial conditions, loadings, and parameter values must be specified for each component.

Initial Conditions. Initial conditions for the Four Mile Creek channel were estimated from suspended sediment particle size data and bed core samples gathered as part of the ISU field study. The data indicated a suspended sediment concentration of approximately 40 mg/l in the Lincoln/ Traer channel at the beginning of the calibration period (April 1, 1978). Particle size analysis indicated that the suspended material was almost entirely silt and clay with about 60% of the total being clay. Initial bed depth for Four Mile Creek was approximated as 0.3 m, based on cross-sections reported by Johnson (1978). These cross-sections contain ground lines and "bottom-of-sediment" lines which enable the bed depth approximations. Bed core samples collected by ISU supported the following initial bed composition for the simulation runs:

Bed Composition

Reach	% sand	% silt	% clay
1-3	60	20	20
4-8	50	25	25

Sediment Loadings. Module section SEDMNT was used to simulate the total sediment loading to Four Mile Creek associated with runoff from pervious land segments. Runoff quantities were developed using one rainfall record which was a weighted mean record based on the four records used for the watershed hydrologic calibration and the relative area represented by each of the records. Since results from section SEDMNT are expressed as total sediment, it was necessary to divide the total sediment loading into sand, silt, and clay as input for the instream simulation performed by SEDTRN. Load weighted particle size distribution curves for selected runoff events were developed by ISU for selected storms at both the small (Sites 1, 2, 3) and large (Sites 4, 5) basin sample sites. Analysis of these curves indicated only a small amount of sand in sediment loadings to Four Mile Creek from storm washoff. Between 50 and 65 percent of measured sediment loading is silt, and 35 to 50 percent is clay. It is likely that a portion of the runoff sediment from the croplands is sand but that this portion settles out at the sampling sites, which are typically characterized by slower velocities than the open channel. It was assumed that sand particles are trapped in vegetation on meadow lands and do not run off. Based on the ISU data, we assumed the following distribution of sediment fractions in runoff from the soybeans, corn, and meadow/other areas:

HSPF Segment	Land Type	Runoff Sediment Composition		
		% sand	% silt	% clay
PLS 1	soybeans	5	55	40
PLS 2	corn	5	55	40
PLS 3	meadow/other	0	60	40

Parameters for sediment simulation. Simulation of sand transport was performed using the Toffaleti method. This method is dependent only on water temperature and the hydraulic properties of the channel, and consequently requires no additional input parameters. Simulation of silt and clay is dependent on six parameters, three of which are determined by calibration. The parameters, the basis for value selections, and final parameter values are summarized in Table 5.8.

Calibration procedures. Sediment simulation with HSPF only allows calibration of cohesive sediments (i.e., silt and clay). The three parameters used for calibration quantify the critical shear stress for deposition (TAUCD); critical shear stress for erosion (TAUCS); and the rate of erosion, or erodibility coefficient (M). Successful calibration of instream sediment loadings and concentrations requires a five-step procedure:

1) Using the hydraulic calibration, identify a period of record which contains events which have the best fit between recorded and simulated flows. Sediment transport processes are strongly linked to hydraulic processes, and the sediment calibration requires an accurate hydraulic representation in order for values derived for TAUCD, TAUCS, and M to be meaningful. A calibration period of April - June 1978 was selected based on this criterion and data availability.

TABLE 5.8 SELECTED PARAMETER VALUES FOR INSTREAM SEDIMENT SIMULATION IN FOUR MILE CREEK

PARAMETER	DEFINITION	VALUE			BASIS FOR SELECTION
		SAND	SILT	CLAY	
D	Effective Particle diameter (mm)	.356	.0160	.00140	ASCE Sedimentation Engineering (p.20)
W	Fall velocity of particle in still water (mm/sec)	63.5	.168	.00086	Stokes Law
RHO	Density of particle relative to water	2.65	2.2	2.0	Handbook of Chemistry and Physics
TAUCD	Critical bed shear stress for deposition (kg/m2)	-	0.25	0.20	Calibration
TAUCS	Critical bed shear stress for scour (kg/m2)	-	1.00	0.75	Calibration
M	Erodibility coefficient (kg/m2 day)	-	15.	37.	Calibration

2) Use the HSPF DISPLY function to output daily values for calculated shear stress, TAU. Identify the range of values for TAU which are characteristic of periods which exhibit significant suspension of sediment in the historical data.

3) Set values for the critical shear stress for erosion of silt and clay which bracket the period of increased suspended load. Proper selection of values for TAUCS should result in scour and suspension of noncohesive materials during periods of increased flow and shear stress, but no erosion during periods when the historical record shows minimal suspended sediment. Values of 1.0 and 0.75 kg/m2 were derived for critical shear stress for silt and clay, respectively. These values were used for all eight reaches of Four Mile Creek. Given the fact that shear stress is a function of reach slope and hydraulic radius, values for TAU vary from reach to reach, and hence at any given time in the calibration, erosion may be occurring in one reach and not in others. Since the recorded sediment data are for Reaches 1 and 2, the selected values for TAUCS must result in the best cumulative fit at the downstream reaches.

4) By examining calculated values for TAU during low flow, less turbulent portions of the simulation record, select values for TAUCD for silt and clay which only allow deposition during appropriate periods. Values of 0.25 and 0.20 kg/m2 were selected for silt and clay, respectively.

5) Adjust the erodibility coefficient, M, to obtain the best overall correspondence between observed and simulated pollutographs for events with good hydraulic fit. For the three month sediment calibration period of Four Mile Creek, values for M of 15. and 37. kg/m2-day were appropriate.

Calibration/verification results. The daily sediment loadings and flow at Traer are illustrated in Figure 5.8, and monthly loadings summaries are provided in Table 5.9. In general, the calibration results were good. During the three month calibration period there were six significant peaks in sediment loading (Figure 5.8, bottom graph). Of the six peaks, Peak #3 and #6 are simulated most closely. These events, along with Peak #4, have the closest agreement between simulated and recorded flow, (Figure 5.8, top graph) and hence it is appropriate that most attention be given to accurately representing them in the calibration process. The accuracy of the historical data for Peak #4 is questionable.

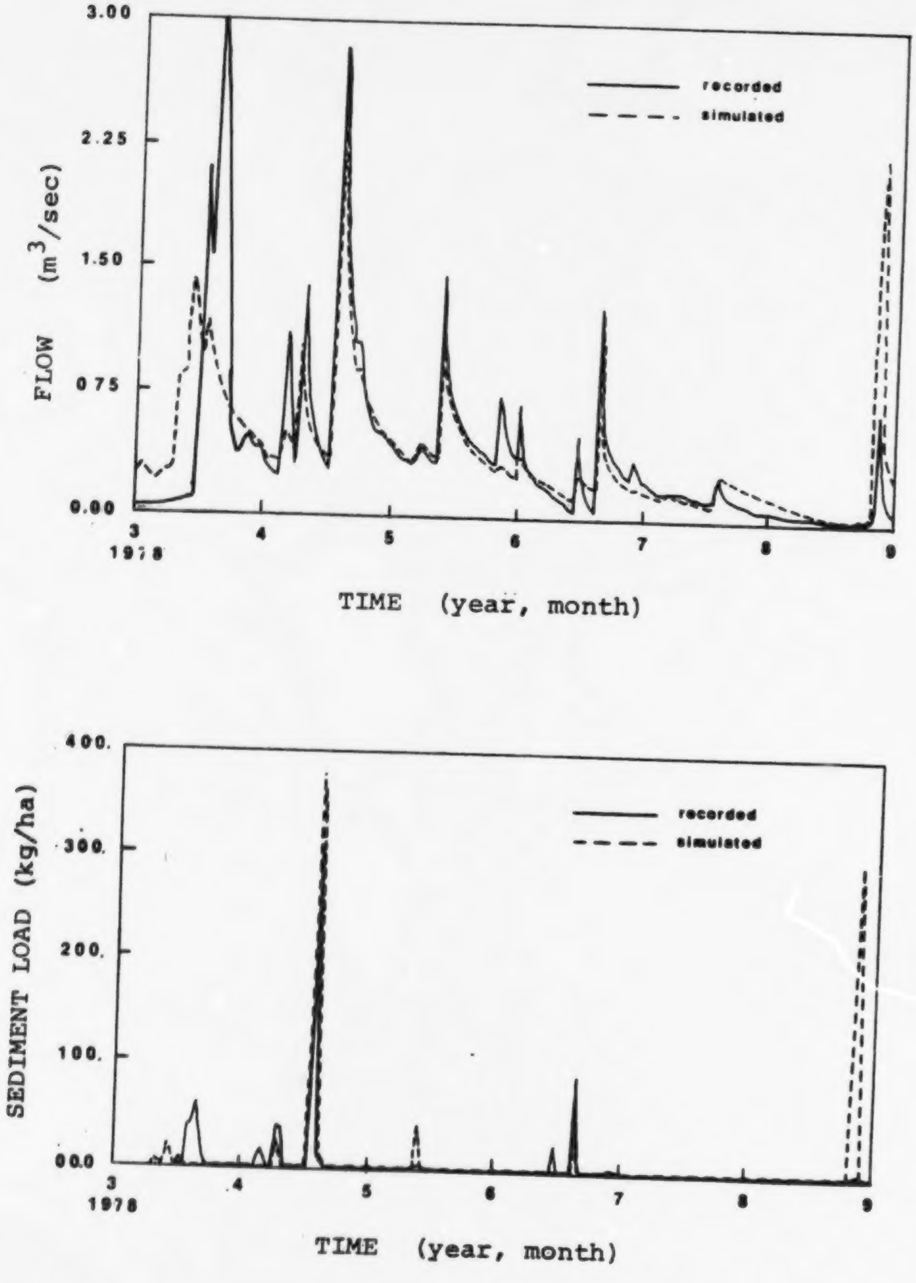


Figure 5.8 Calibration results for flow (top) and sediment loading (bottom) at Traer, IA.

TABLE 5.9 MONTHLY SUMMARY OF SEDIMENT SIMULATION RESULTS AT TRAER FOR CALIBRATION AND VERIFICATION PERIODS (Edge-of-stream loadings are included for comparison)

	SEDIMENT (kg/ha)		
	RECORDED (at Traer)	SIMULATED (at Traer)	SIMULATED (Edge-of-stream)
CALIBRATION			
1978			
APRIL	510	567	199
MAY	30	46	12
JUNE	150	72	25
TOTAL	691	685	236
VERIFICATION			
1976			
APRIL	751	265	76
MAY	95	0	1
JUNE	235	167	59
JULY	2	0	0
AUGUST	0	0	0
SEPTEMBER	0	0	0
TOTAL	1083	432	137

The majority of the sediment load at Traer can be attributed to scour and consequently is strongly influenced by flow. Since the recorded peak value for flow during Event #4 is comparable in magnitude to peak values for Events #1 and #2, it is unclear why considerable sediment load was recorded for Events #1 and #2, and not for Event #4. Of the three remaining sediment load events, the calibration fit was good for Event #2, but poor for Events #1 and #5. Given the simulated loadings from the land surface, simulated hydraulic conditions, and the set of values for instream sediment calibration parameters which produce reasonable results for other events, these two sediment peaks cannot be reproduced by the same simulation run. Total simulated sediment loadings for April - June 1978 were 685 kg/ha or approximately 3450 tonnes. Of this total, slightly more than 1200 tonnes (35%) resulted from surface washoff, while the remaining loadings were the result of channel scour. Scour resulted in a net decrease of bed depth of .01 m at Traer. Less than 5 percent of total sediment load at Traer was sand, while silt and clay contributed 25 and 70 percent, respectively.

After values for sediment calibration parameters were finalized, the period from April 1976 to September 1976 was simulated for model verification. 1977 data were not used for verification because drought conditions that year resulted in unusually low sediment loadings and very few events of substantial washoff or scour. Daily sediment loadings and flow at Traer for the verification period are illustrated in Figure 5.9. Monthly total sediment loadings at Traer are also presented in Table 5.9. In addition, monthly total edge-of-stream loadings are included to provide an indication of the relative importance of sediment loadings versus channel scour/deposition. The verification period simulation resulted in approximately 440 kg/ha (2180 tonnes) of sediment loading at Traer, with 31% of the total attributable to land surface washoff. Undersimulation of flow (Figure 5.9, top graph) contributed to a consistently low simulation of sediment loadings for the verification period.

While the comparison of recorded versus simulated total sediment loadings is not good (1085 kg/ha recorded vs. 440 kg/ha simulated), the model appears to do a reasonable job of determining the relative importance of washoff versus scour contributions to sediment loadings. Research performed by Kimes et al., (1979) indicates that approximately 60 percent of the loading at Traer has resulted from channel scour over the past 10 years and that the channel bottom is degrading at a rate of 0.03 m/yr. Simulation results from 1976 and 1978 indicate a 60-65 percent contribution to loading from scour. Net change in bed depth was not available from the HSPF simulation results on an annual basis, but changes in bed depth for simulated periods suggest an annual decrease in bed depth of less than half that was calculated by Kimes. Although Kimes states that bed erosion

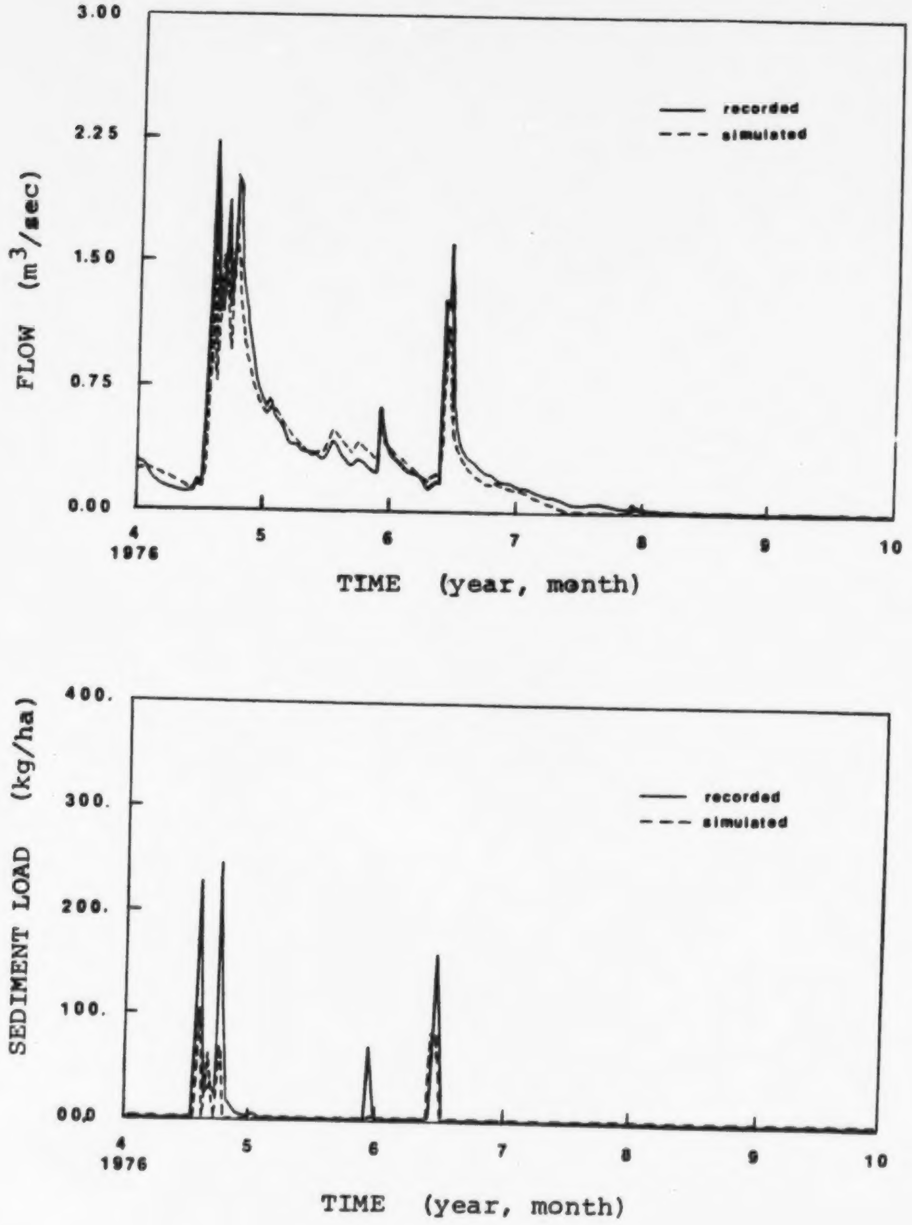


Figure 5.9 Verification results for flow (top) and sediment loading (bottom) at Traer, IA.

has been proceeding at a slower rate than typical during recent years (1977-1979), the undersimulation of 1976 sediment loadings, combined with low values for bed degradation, suggest that further adjustment of calibration parameters may be warranted. However, the overall representation of the instream sediment process is sufficient for subsequent pesticide modeling, especially since the majority of the pesticide is transported in soluble form.

5.7 Instream simulation of alachlor

After completion of the land surface hydrology, sediment, and pesticide simulation, and the instream hydrology and sediment transport simulation, the instream simulation of alachlor was performed. The calibration and verification results for alachlor simulation on Four Mile Creek are shown in Figures 5.10 and 5.11 for alachlor concentrations and loadings, respectively. These results are based on the small site sediment and pesticide parameters, the hydrology parameters calibrated on the entire watershed, and the resulting instream hydraulics and sediment transport simulation previously discussed. Instream pesticide parameters, such as partition coefficients and decay rates were also calibrated, but the major effort involved in simulating pesticide loss from the entire watershed was related to extrapolation of pesticide application rates, methods, and timing for the watershed as a whole.

Although the specific dates, amounts, and method of chemical applications were recorded for the small field sites, analogous information for the 67 farmers in the Four Mile Creek watershed was not available. Inventory data collected by Iowa State University indicated the total amount of chemicals applied within the watershed and approximate percentage of cropland which received applications. From this information application rates on the actual cropland receiving alachlor were developed and used in our simulations, along with the assumption that surface application of alachlor was the primary application method.

The sequence and timing of alachlor applications in Four Mile Creek has a major impact on the resulting simulation. In reality, farmers will usually apply pesticides like alachlor to cropland in a 3 to 4 week period usually in May and June; a normal distribution about a mean or average date of application can usually be assumed. However, using a lumped parameter modeling approach like that used in HSPF, it is not possible to specify application dates and amounts for individual farmers on a complex watershed like Four Mile Creek. The model requires the specification of specific dates and amounts of a chemical being applied which must approximate the actual application operations.

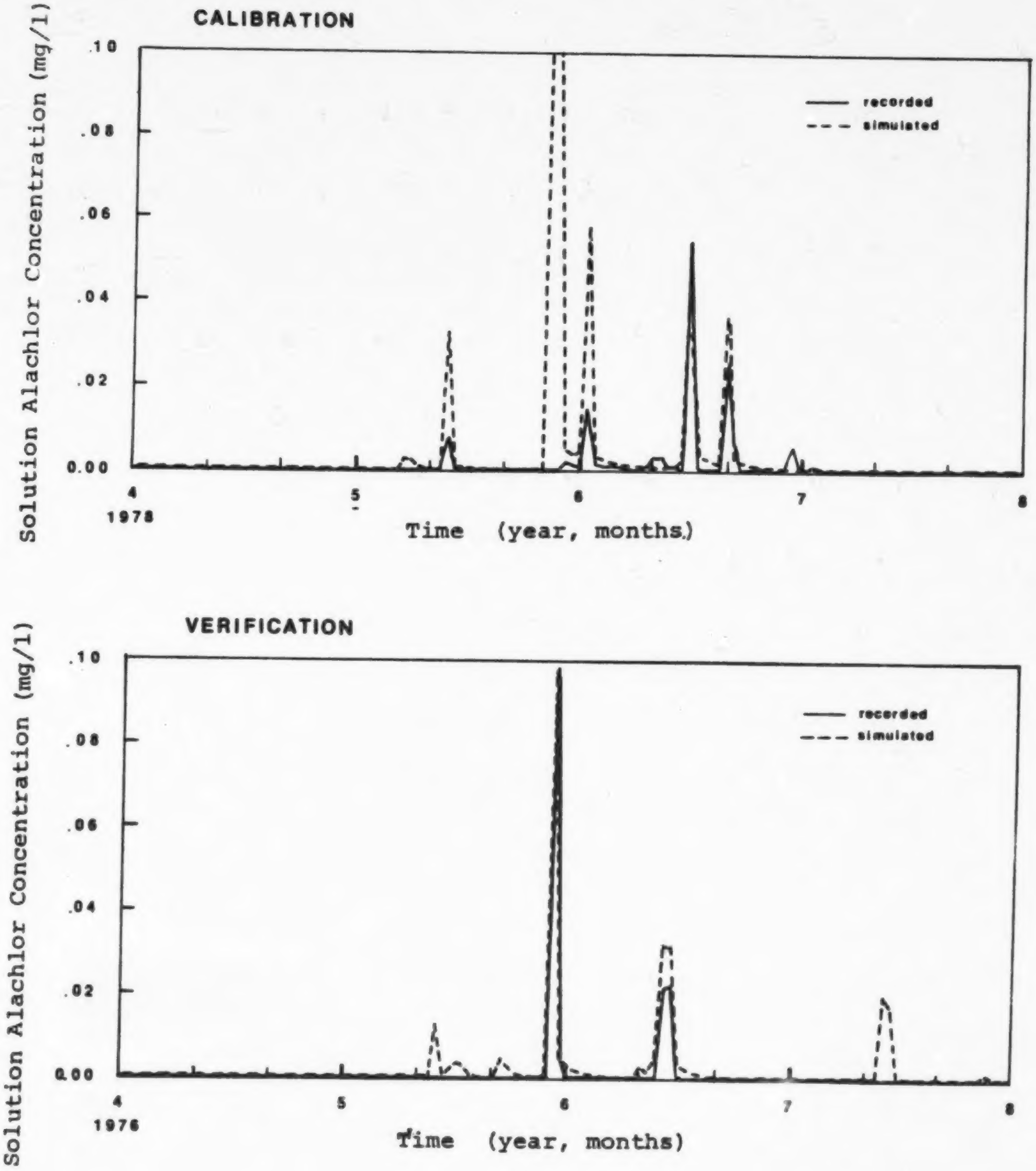
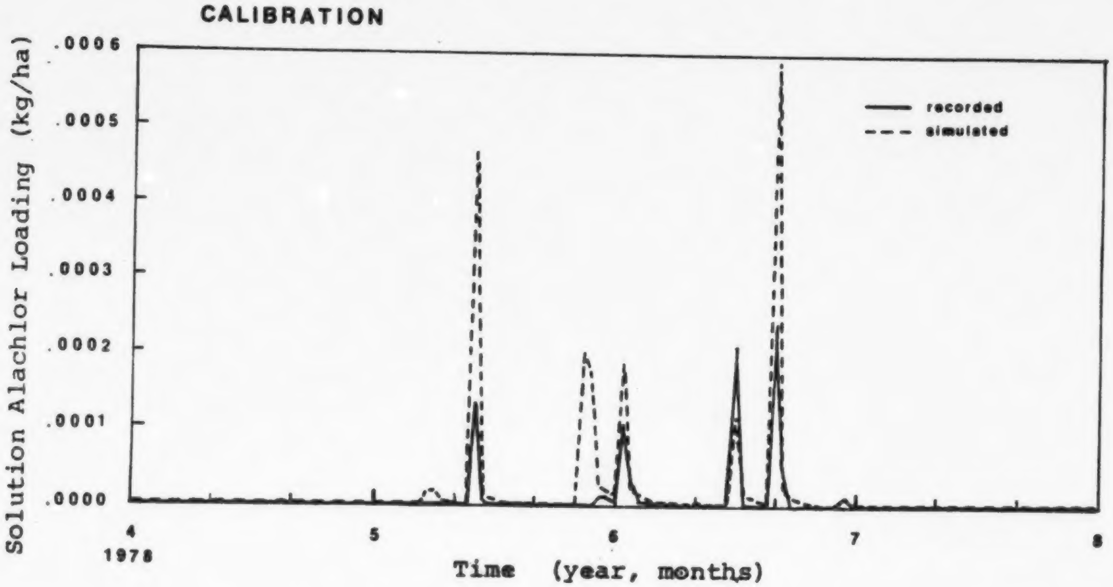


Figure 5.10 Calibration and Verification results for Solution Alachlor concentration at Traer, IA.



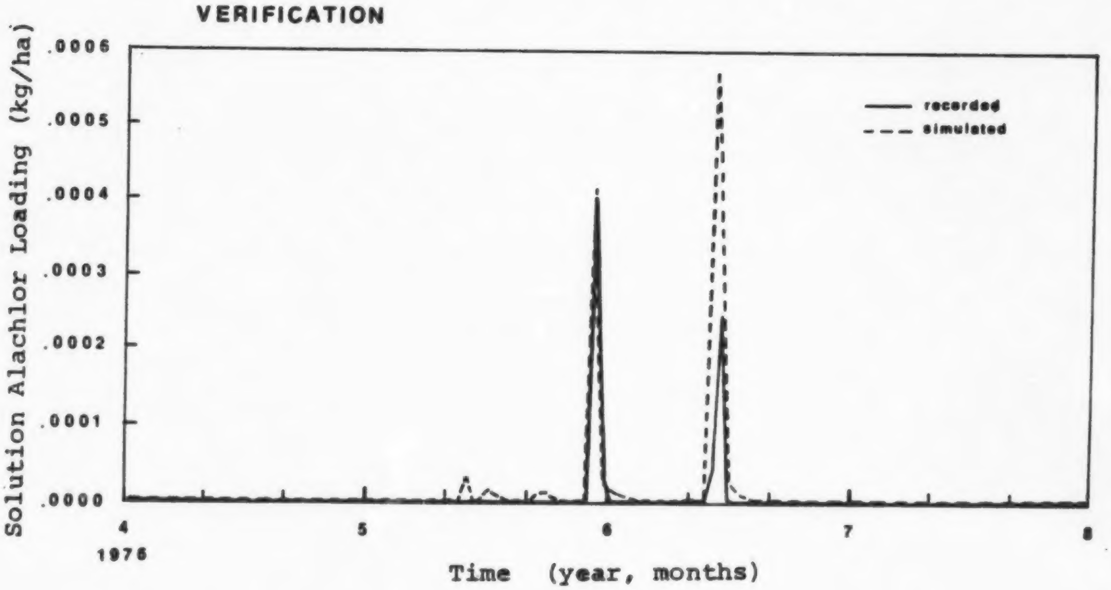


Figure 5.11 Calibration and Verification results for Solution Alachlor loading at Traer, IA.

The relative timing of applications and the first significant storm event have a major impact on the resulting chemical runoff. Initial simulation runs indicated that the assumption of a single application date, time, and amount in the spring of each year produced a worse case scenario whereby the first significant runoff event following the application would result in major chemical losses. Consequently, the application amounts were divided into 3 separate applications corresponding to 25%, 50%, and 25% of the total estimated application amount; this was an effort to use a triangular distribution that would approximate the normal distribution actually occurring in the field. Table 5.10 indicates the dates and the amounts of alachlor applications assumed for the soybeans and corn segments for both the calibration and verification periods.

Ideally, the 3 separate applications would best be represented by 3 separate land segments corresponding to each of the areas receiving alachlor applications on different dates. However, this type of representation would result in a tripling of the simulation costs due to the additional land segments that would need to be simulated. Consequently, the applications were divided as shown in Table 5.10 in an attempt to develop a reasonable approximation of the alachlor application distribution actually occurring in the field, while minimizing the resulting computer costs.

Since only 40% to 50% of the soybeans and corn cropland in Four Mile Creek receives alachlor applications each year, the per acre alachlor loadings determined by the land surface simulation were then multiplied by only that amount of cropland (soybeans or corn) that actually received a chemical application. This was performed for each channel reach throughout the Four Mile Creek system in order to represent the alachlor loadings throughout the watershed

The instream pesticide parameters used for alachlor are shown in Table 5.11. The effort on the instream alachlor simulation was concentrated on evaluating partition coefficients for the sand silt and clay fractions; decay rates for solution, suspended, and sediment alachlor; and the transfer rates for reaching or approaching equilibrium. Since very little information or experience currently exists regarding the transfer rates, a major portion of the instream simulation was devoted to gaining some familiarity with the relative range of values that might be expected for each parameter. Initial partition coefficients and decay rates were obtained from recommendations by SRI International (Bomberger, 1980), work by Schnoor (1980), and other information available in the literature. It should be noted that the decay rates used for alachlor for the stream and bed conditions are values at 35 degrees centigrade with the resulting temperature correction used to adjust these rates to

TABLE 5.10 AMOUNT AND TIMING OF ALACHLOR APPLICATIONS ASSUMED IN FOUR MILE CREEK, IA. (kg/ha)

	SOYBEANS - PLS 1		CORN - PLS 2	
	Date	Amount	Date	Amount
CALIBRATION - 1978				
	5/25/78	0.63	5/1/78	0.67
	6/3/78	1.26	5/15/78	1.32
	6/10/78	0.63	5/20/78	0.67
	Total	2.52		2.66
VERIFICATION - 1976				
	5/18/76	0.71	5/5/76	0.71
	5/25/76	1.40	5/10/76	1.40
	6/2/76	0.71	5/17/76	0.71
	Total	2.82		2.82

TABLE 5.11 VALUES OF SELECTED PARAMETERS FOR INSTREAM SIMULATION OF ALACHLOR IN FOUR MILE CREEK

ALACHLOR DECAY PARAMETERS	RATE at 20 C (/day)	TEMPERATURE CORRECTION COEFF.
Solution	0.08	1.07
Suspended Sediment	0.10	1.07
Bed Sediment	0.12	1.07

PARTITION COEFFICIENTS (ml/gm)	SAND	SILT	CLAY
Suspended Sediment	2.	10.	50.
Bed Sediment	10.	5.	100.
ADSORPTION/DESORPTION RATE PARAMETERS (/day)			
Suspended Sediment	8.0	8.0	8.0
Bed Sediment	0.03	0.03	0.03

actual stream temperatures; average monthly stream temperatures based on observed data were used in these simulations.

The primary effort in the instream pesticide calibration was devoted to evaluating the relative sensitivity of the transfer coefficients which indicate the rate of approach to equilibrium partitioning. With extremely high values for these transfer rates, essentially all pesticide that is input to the stream is instantaneously adsorbed to available sediment both being transported in the stream and resident in the bed. The pesticide then gradually desorbs back into the flowing water resulting in pesticide concentrations existing instream for long periods of time. More reasonable values for the transfer rates, such as those shown in Table 5.11, produce the transient behavior shown in Figures 5.10 and 5.11.

Although the alachlor simulations are generally higher than observed values, the concentrations and loads are generally within the range of the observed values. Moreover, the simulation duplicates the generally spiked nature of the alachlor concentrations resulting from individual storm events occurring closely following the chemical application period. The major discrepancy in Figure 5.10 was unexplained until it was discovered that samples were not collected, inadvertently, during the storm events that occurred on May 29, and June 1. Figure 5.12 compares the detailed hourly simulation of solution alachlor concentrations with the observed sample data. Clearly, the samples taken on May 27 and June 1 missed the major part of the storm event, resulting in a gross underestimate of the actual alachlor concentrations and loads. Coincidentally, storm events on May 27, 1978 and May 29, 1976 resulted in the same approximate flow peaks and volumes. Thus, using the observed values on May 29, 1976 as a guide, it would appear that the simulated concentrations for the May 27, 1978 storm (Figure 5.10) and the June 1, 1978 storm are reasonably close to what might have been expected if samples had been taken during the peak of the storms.

In general the simulation results shown in Figures 5.10 and 5.11 are quite reasonable, and in fact, the verification period appears to be somewhat better simulated than the calibration period. The larger discrepancies shown in Figure 5.11 for alachlor loading reflect the combined errors in both the simulated flow and simulated alachlor concentrations. However, it is clear that the observed data also include errors and the grab sampling procedure used would likely tend to underestimate the loads.

Table 5.12 shows the recorded and observed alachlor loading at Traer for May and June of 1976 and 1978, along with the simulated stream loading and land surface loads from the corn and soybeans croplands. The simulated solution loads at Traer are

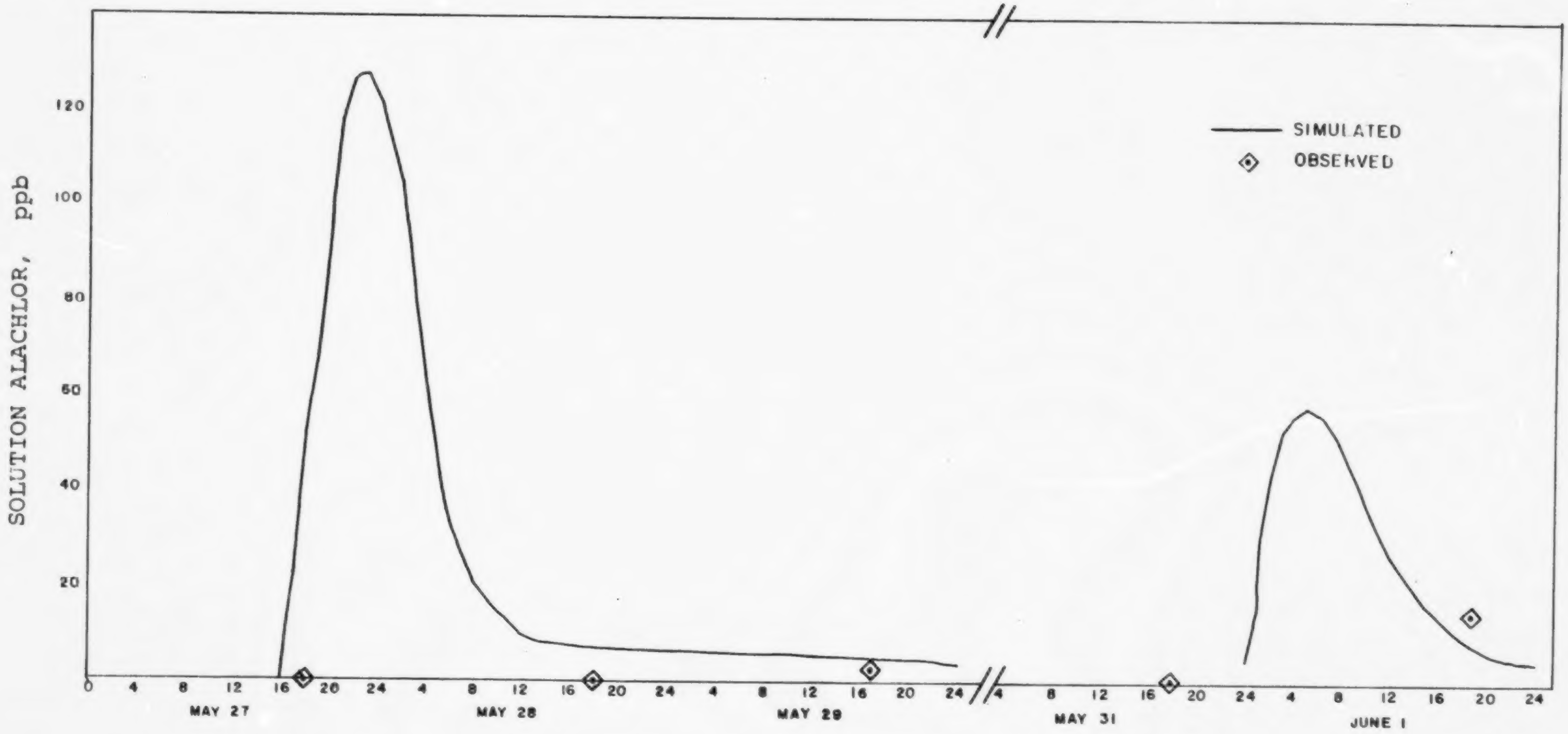


Figure 5.12 Comparison of detailed hourly simulation of solution alachlor concentration with observed data.

TABLE 5.12. CALIBRATION AND VERIFICATION RESULTS FOR ALACHLOR ON FOUR MILE CREEK, IA.

	ALACHLOR LOADING (kg/ha)									
	RECORDED		SIMULATED							
	TRAER		TRAER		STREAM LOADING		SOYBEANS		CORN	
	SOL	SED	SOL	SED	SOL	SED	SOL	SED	SOL	SED
CALIBRATION:										
1978										
MAY	.0002	0	.0010	.00003	.0017	0	.0026	0	.0054	.00002
JUNE	.0007	0	.0011	.00007	.0013	.00001	.0085	.00003	.0018	.00001
TOTAL	.0009	0	.0021	.00010	.0030	.00001	.0111	.00003	.0072	.00003
VERIFICATION:										
1976										
MAY	.0004	.00002	.0005	.00009	.0010	0	.0050	0	.0018	0
JUNE	.0003	.00003	.0010	.00012	.0014	.00002	.0089	.00008	.0018	.00003
TOTAL	.0007	.00005	.0015	.00021	.0024	.00002	.0139	.00008	.0036	.00003

SOL - Solution Alachlor
SED - Sediment Alachlor

approximately twice the observed values. The simulated sediment alachlor is considerably higher than the observed values, but it should be noted that the simulated values border on the edge of computer accuracy for the computer systems used in this simulation. Thus the final digits noted in Table 5.12 are subject to considerable error.

The simulated stream loadings shown in Table 5.12 which were derived from the land surface loadings and the fraction of the area contributing alachlor loads, are approximately 30% higher than the loadings measured at Traer. Thus, approximately 30% of the alachlor reaching the stream does not reach the watershed outlet at Traer due to adsorption onto sediment particles, resulting deposition in the bed, and decay of the compound in the channel bed. The same relative amounts of alachlor that decay in the stream are shown to occur in both the calibration and verification periods.

Risk Assessment and Model Verification. Another method of viewing calibration and verification results is to determine whether decisions on risk or exposure to aquatic organisms would be different if the analyst based his decision on the simulated or the observed chemical information. Figure 5.13 demonstrates how the frequency, or percent of time, of acute, chronic, and sub-lethal conditions might be determined for a particular stream given a time series of chemical concentrations. This methodology was developed in work by Onishi et al. (1980) in developing a procedure to assess the risk to aquatic organisms. Using these procedures the observed and simulated chemical concentrations were analyzed to determine percent of time conditions within each region shown in Figure 5.13 would exist. The results of this analysis are shown in Table 5.13; the table title indicates a hypothetical organism because all the values observed for alachlor concentrations were considerably lower than any of the MATC (maximum acceptable toxicant concentration) values for all species of fish found in Four Mile Creek.

Table 5.13 shows that the observed and simulated values agree quite closely indicating that the ultimate decision on aquatic risk and exposure would be the same whether the observed or simulated values were used. Moreover, the sampling errors in 1978 discussed above would increase the observed values in Table 5.13 by 2 percentage points for the acute regions in 1976 and 1978, and by 1/2 percentage point for the 1976-1978 period. This would further increase the agreement between the observed and simulated values.

In summary, the instream pesticide simulation results show that reasonably good simulations can be obtained by using small site parameter values for alachlor in conjunction with hydrologic parameters calibrated on the entire watershed and a reasonably

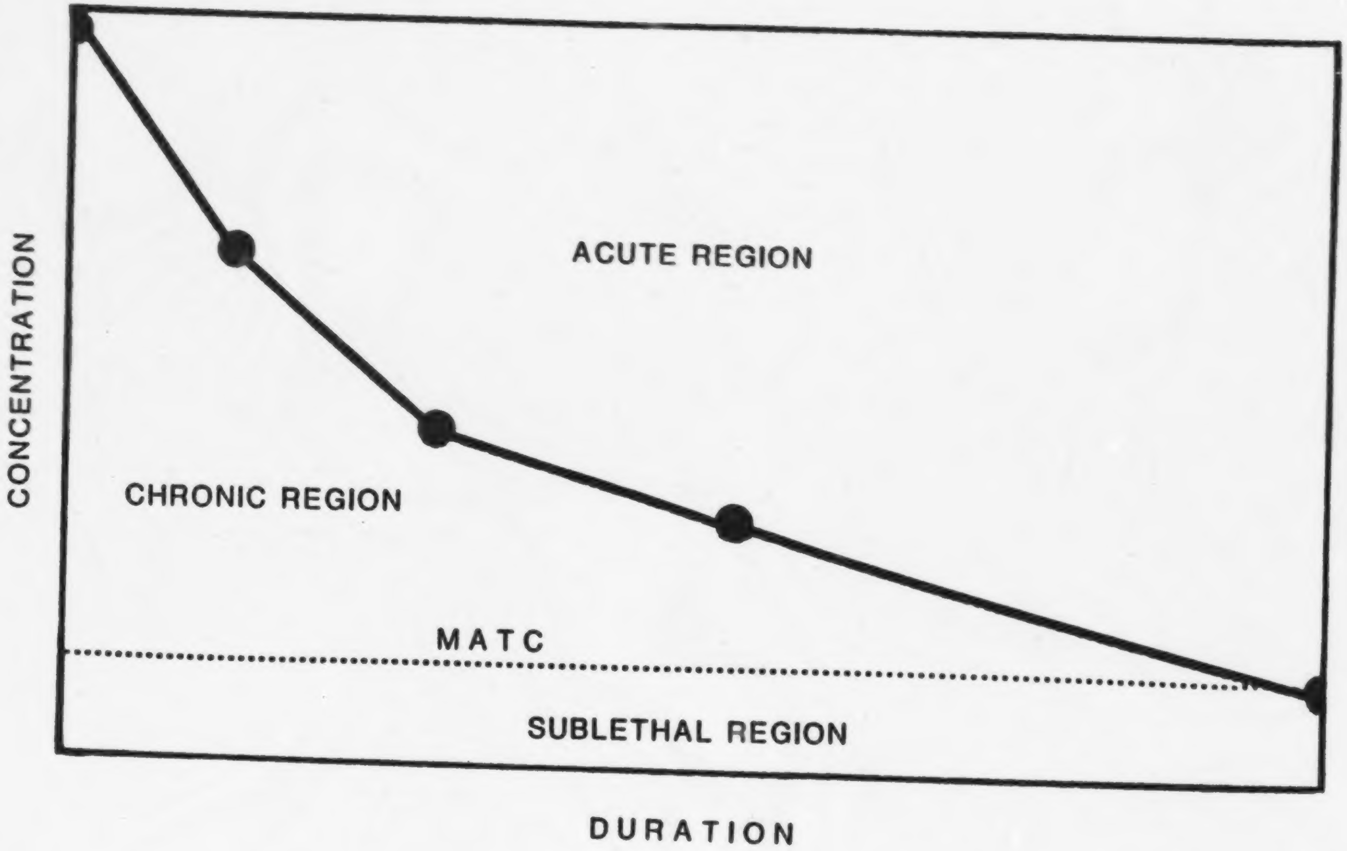


Figure 5.13 Lethality Analysis of Chemical Concentration Data.

TABLE 5.13 LETHALITY ANALYIS FOR ALACHLOR IN FOUR MILE CREEK, IA. (Hypothetical organism)

	GLOBAL EXCEEDANCE (% of time)					
	1978 CALIBRATION		1976 VERIFICATION		1976 - 78	
	OBS	SIM	OBS	SIM	OBS	SIM
ACUTE REGION	0.5	3.3	0.5	1.9	0.2	1.2
ABOVE MATC VALUE	4.4	6.6	3.3	8.1	1.5	3.2
SUBLETHAL REGION (below MATC)	95.6	93.4	96.7	91.9	98.5	96.8

MATC - Maximum Acceptable Toxicant Concentration
(0.003 mg/l used above)
OBS - Observed values
SIM - Simulated values

good instream hydraulic and sediment transport simulation. In effect, this work has shown that an adequate simulation of the hydrologic transport components on a watershed basis provides a viable means of simulating chemical transport and fate. Results in Table 5.13 demonstrate that ultimate decisions on aquatic risk and exposure on this particular watershed, and with the assumed lethality information used in this analysis, would be essentially the same using either the simulated or observed values. Thus the modeling provides a viable means of assessing aquatic risk and exposure since it could be used in place of actual observed data, which is generally not available.

5.8 Nutrient simulation

The nutrient simulation followed much the same general procedures as the pesticide simulation discussed above. Nutrient parameters were initially calibrated on soil core and runoff data from the small sites which were cropped in corn, soybeans, and pasture. Using these calibrated parameters, the simulation was extrapolated to the entire watershed with the resulting simulated and recorded nutrient concentrations and loads compared at the watershed outlet. Parameters for transformations and interactions in the groundwater zone, which could not be determined from the soil core data on the small sites, was extrapolated from the parameter values in the lower zone and then adjusted through calibration of low flow nutrient conditions at the watershed outlet.

Nutrient calibration of soil parameters and processes is more an art than a science due to the many interactions and transformations that occur in the soil profile. The general calibration procedures we developed for this study are as follows:

a. Evaluate initial soil nutrient parameters from information available in the literature, and include fertilizer and rainfall sources of nutrients as input to the model;

b. Calibrate initial mineralization rates so that annual amounts of plant-available nutrients correspond to expected values (we assumed 40 to 60 kg/ha of nitrogen and 15 to 30 kg/ha of phosphorous was mineralized each year);

c. Adjust leaching factors based on any data available for a tracer such as chloride;

d. Adjust plant uptake rates to develop the expected nutrient uptake distribution during the growing season and the estimated total uptake amount expected for the crop;

e. Adjust nutrient partition coefficients based on available core and runoff data;

f. Refine the leaching, uptake, and partition parameters based on observed runoff data and the expected sources of nutrient runoff, i.e., surface, interflow, groundwater.

The above procedures were followed in calibrating the nutrient soil parameters to the observed core and runoff data for the small sites in Four Mile Creek. Since only the surface runoff component was present on the small sites, comparisons of nutrient runoff (simulated and observed) were performed only on an annual and monthly basis for the surface component.

As with the pesticide simulation, the nutrient parameters calibrated on the small sites were then extrapolated to the entire watershed and used in conjunction with the watershed hydrology and stream hydraulics to simulate nutrient concentrations and loadings at the watershed outlet. Since much of the total observed nutrient runoff at the watershed outlet is derived from subsurface sources, observed values at Traer were compared with the total instream nutrient load derived from surface runoff, interflow, and groundwater. The problem of timing, amounts, and method of chemical applications as discussed above for pesticide simulation also affected the nutrient simulation. However, since nutrients are native to the soil profile and do not exhibit rapidly decaying behavior as pesticides do, the timing between a fertilizer application and subsequent runoff events is important, but not quite as critical as for rapidly decaying pesticides.

A problem unique to the nutrient simulation resulted from the fact that nutrients are contributed from all land within the watershed whether or not the land receives fertilizer applications. Consequently, five pervious land segments were needed in the nutrient simulation to represent the five following conditions:

a. Soybean land receiving fertilizer;
b. Corn land receiving fertilizer;
c. Other/pasture land receiving fertilizer;
d. Soybean land not receiving fertilizer;
e. Other/pasture land not receiving fertilizer.

Fertilizer application amounts and associated crop acreages were determined from inventory data collected by Iowa State University. Assumed distribution and timing of nitrogen fertilizer application included 30% application in the fall incorporated by fall plowing, 50% application in spring incorporated by disking, and 20% application in the summer applied as a side-dressing; phosphorous and chloride applications were assumed to occur at the rate of 40% of the annual application in the fall and 60% in the spring.

Preliminary nutrient calibration results for the period of Nov. 1977 through Oct. 1978 are summarized in Table 5.14, and the nitrate, ammonia, and chloride concentration and load simulations are shown in Figures 5.14, 5.15, and 5.16, respectively. The results are preliminary because the small site parameters were used directly at the watershed level with no additional calibration. However, they indicate the general ability of the model to represent nutrient soil processes and resulting ability to simulate nutrients at the watershed level.

Table 5.14 lists the mineralization, denitrification, and plant uptake amounts resulting from the soil nutrient simulation. The mineralization amounts were calibrated to be in the range of expected values. The denitrification amounts are probably low and should be adjusted upward in future calibration efforts; denitrification in this study was not used as a means of completing a mass balance of the nitrogen, as is commonly done in many studies. The plant uptake amounts simulated for the various crops and land uses closely correspond to values actually measured by ISU on the small sites. For example, the nitrogen uptake by corn measured by ISU from Site #2 in 1978 was 189 kg/ha while the watershed simulation was 227 kg/ha; for phosphorous 33 kg/ha was measured and 37 kg/ha was simulated. For soybeans, the simulated nitrogen uptake of 76 kg/ha reflects our assumption that 30% to 35% of the total uptake is derived from the soil. Thus, the 76 kg/ha value represents a total nitrogen uptake of 220 to 250 kg/ha; ISU measured a nitrogen content of 229 kg/ha for soybeans on Site #1 in 1978. For phosphorous uptake by soybeans, the same value of 22 kg/ha was both simulated by the model and measured by ISU.

Table 5.14 also shows the nutrient runoff and components (surface, interflow, groundwater) from the individual land uses; the last two columns compare simulated and observed loads at Traer.

The corn land was a major contributor of nitrate, with 39 kg/ha which was twice the amount from fertilized soybeans. Interflow was a significant component in contributing nutrients to the stream. Chloride contributions are reasonably well divided among the five different land uses shown in Table 5.14. Groundwater was a major contributor of nitrate and chloride from all pervious land segments simulated.

TABLE 5.14. PRELIMINARY NUTRIENT CALIBRATION RESULTS ON FOUR MILE CREEK, 11/77-10/78 (kg/ha)

	SOYBEANS WITH FERTIL.		CORN WITH FERTIL.		OTHER/PASTURE WITH FERTIL.		SOYBEANS WITH NO FERTIL.		OTHER/PASTURE WITH NO FERTIL.			TRAER
	NIT	PHOS	NIT	PHOS	NIT	PHOS	NIT	PHOS	NIT	PHOS	SIMUL	OBSERVED
Mineralization	59.33	24.63	57.09	23.51	39.18	19.03	59.33	24.63	39.18	19.03		
Denitrification	10.07		13.43		5.04		7.05		2.69			
Plant uptake	76.12	22.39	227.24	36.94	59.33	10.41	59.33	19.03	32.46	7.72		
NO3 Runoff												
Surface	0.027		0.033		0.20		0.027		0.040			
Interflow	4.93		15.67		2.13		3.13		1.04			
Groundwater	15.67		23.51		3.81		12.31		3.47			
Total	20.60		39.18		6.04		15.45		4.48		25.75	20.15
NH3 Runoff												
Surface	0.21		0.34		2.69		0.21		0.16			
Interflow	1.10		3.36		2.24		0.53		0.39			
Groundwater	0.04		0.04		0.09		0.041		0.087			
Total	1.35		3.68		4.92		0.781		0.63		2.2	0.84
Cl Runoff												
Surface	0.029		0.039		1.8		0.029		0.069			
Interflow	13.4		11.2		8.6		3.9		1.9			
Groundwater	25.7		31.3		22.4		21.3		15.7			
Total	39.1		42.5		32.8		25.2		17.6		33.	28.
PO4 Runoff												
Surface	0.12		0.21		1.6		0.12		0.03			
Interflow	1.2		1.9		1.1		1.0		0.56			
Groundwater	0.073		0.071		0.092		0.073		0.092			
Total	1.3		2.1		2.7		1.1		0.68		1.7	0.2

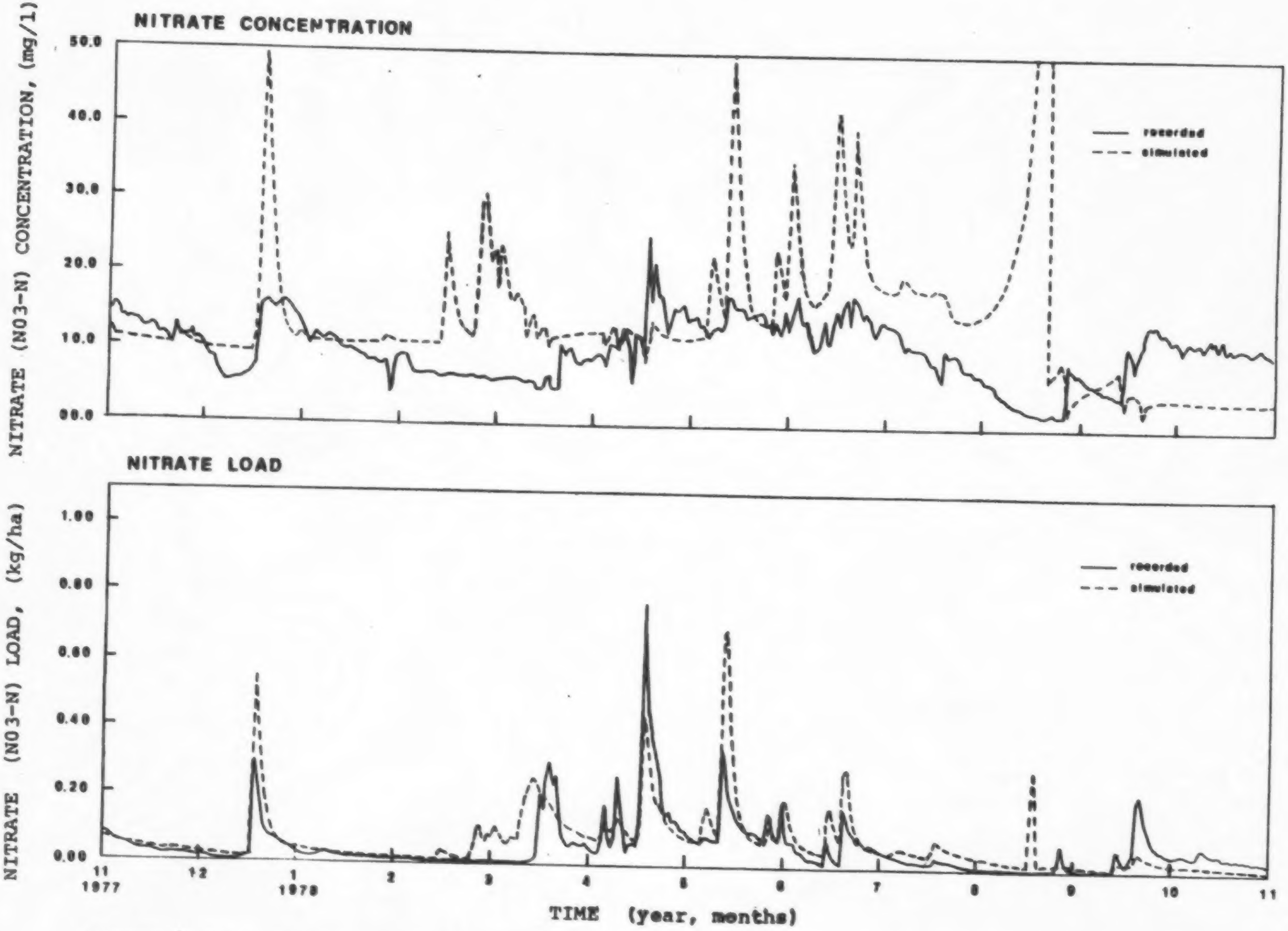


Figure 5.14 Nitrate (NO3-N) Concentration and Load at Traer, IA. - Recorded and Simulated.

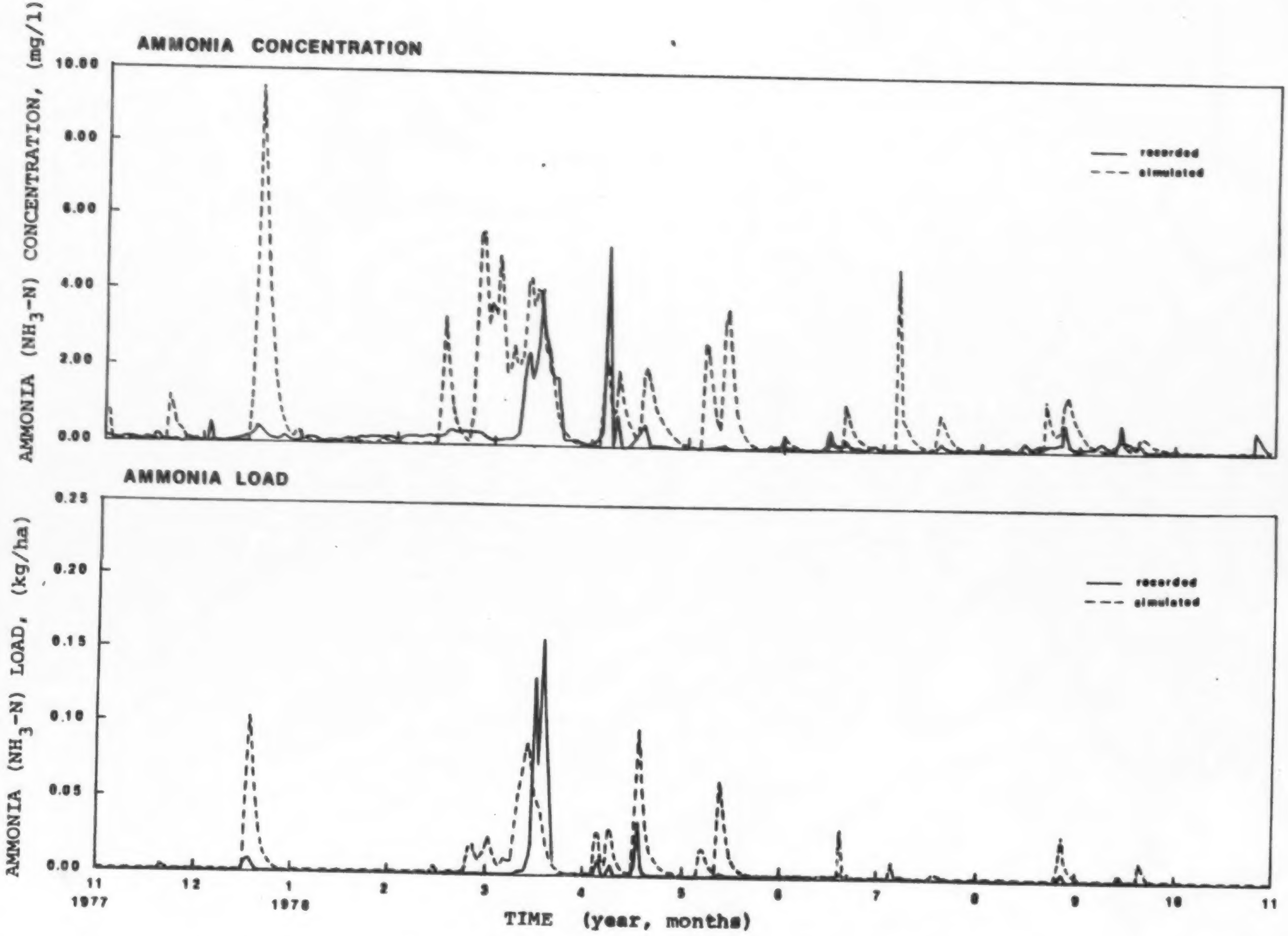


Figure 5.15 Ammonia (NH_3-N) Concentration and Load at Traer, IA. - Recorded and Simulated.

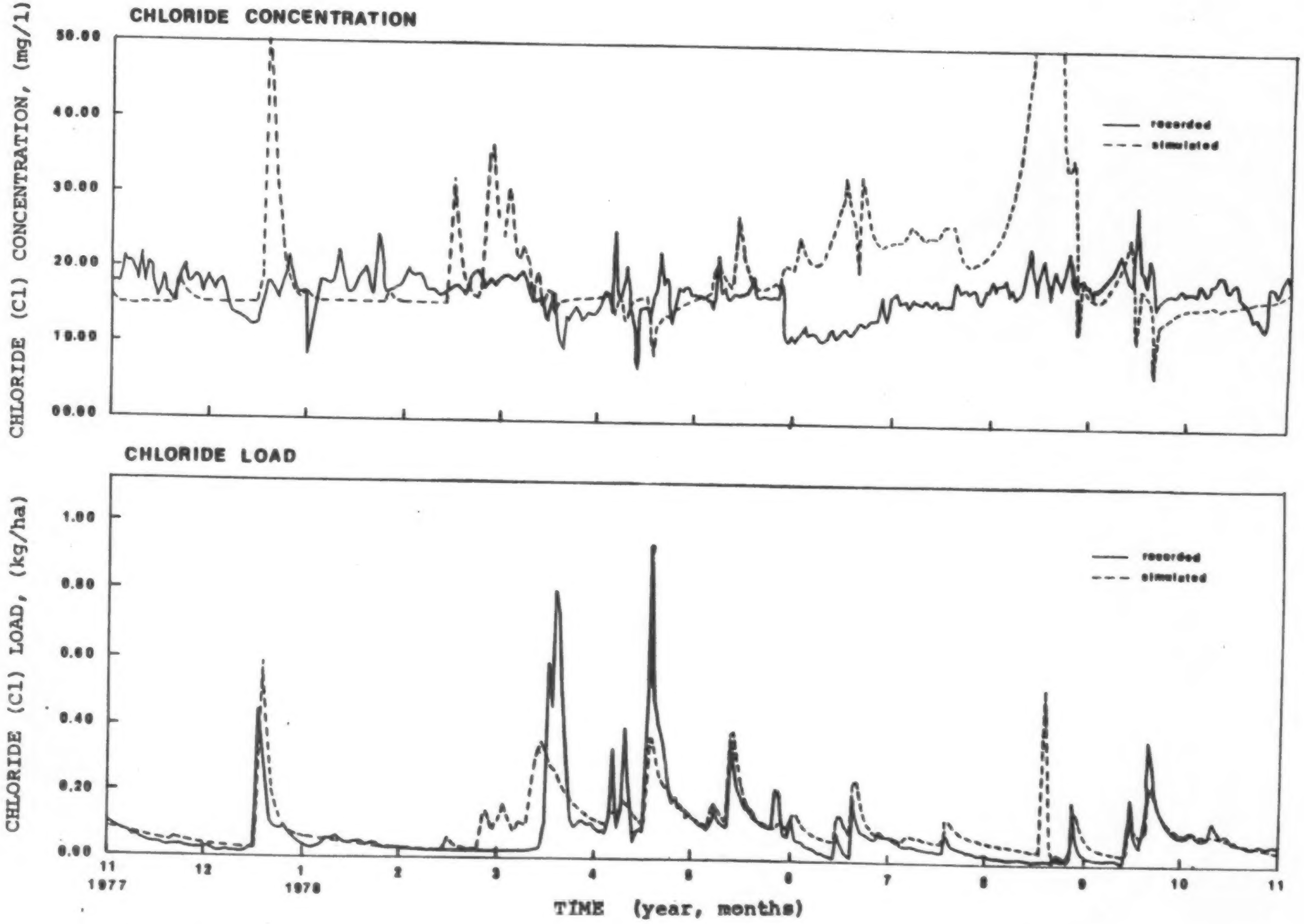


Figure 5.16 Chloride (Cl) concentration and lead at Traer, IA. - Recorded and simulated.

The large differences between the ammonia and phosphate simulated and recorded values at Traer are primarily because instream sediment and sediment-nutrient interactions were not simulated. Few data on sediment associated nutrients were available for the instream sites, and the RQUAL section of HSPF does not simulate sediment-nutrient interactions as is done by the pesticide components of HSPF. This capability to simulate nutrient/sediment interactions should be added in the near future in order to provide more realistic representation of nutrient loadings from a watershed.

In any case, the lack of simulating sediment concentrations and sediment/nutrient interactions contributes to the high estimation of nutrient loadings because the ammonia and phosphate forms would tend to adsorb to the sediment and deposit on the stream bed resulting in a lower total nutrient load and also lower solution concentrations. This same phenomenon in terms of the reduction of loading due to instream processes was observed in the pesticide simulation. Since phosphate is more highly adsorbed than ammonia, the discrepancy between simulated and recorded phosphate loadings at Traer was significantly greater than that for ammonia. Also, a more realistic simulation of ammonia including sediment/nutrient interactions would not only lower the ammonia loadings but would also decrease the nitrate loadings resulting in an improved nitrate simulation.

The daily concentrations and loads from nitrate, ammonia, and chloride shown in Figures 5.14, 5.15, and 5.16 generally indicate that the loads are simulated considerably better than concentration values, and that the overall simulation is reasonably good. The effects of timing of fertilizer applications are quite evident in these figures. The over simulation of the mid-December period is a result of assuming a fall fertilizer application in November. Also, the peaks during April and May are a direct result of assumptions of whether or not fertilizers were applied prior to or following individual storm peaks. For example, in Figure 5.16, the simulated chloride peak in mid-April is considerably lower than the observed peak, while the peak in mid-May is quite good; in a previous run, fertilizer application was assumed to occur prior to the mid-April peak and it resulted in a much better simulation of the April peak and a somewhat lower simulation of the May peak.

The problems of simulating snowmelt timing and runoff volumes, as discussed previously in the hydrologic calibration, evidently have a significant impact on the resulting nutrient simulation as shown in these figures. The over simulation of nitrate and ammonia during the summer period may be partially due to an underestimate of denitrification in the case of nitrate and the lack of sediment/nutrient interactions simulated instream as noted previously.

High chloride concentrations during June and July are essentially unexplained. In fact, an adequate chloride balance could not be obtained from summing rainfall and fertilizer sources of chloride in comparison to soil core measurements and runoff amounts.

The large discrepancies in August indicating increasing nitrate and chloride concentrations, and resulting peaks in nitrate and chloride loads are a direct result of computational errors in the model when base flow conditions approach zero. This error has been corrected in HSPF.

Although the results presented here are preliminary in nature, it is clear that the model is capable of representing the overall watershed system behavior in terms of nutrient simulation. Moreover, additional calibration efforts would significantly increase the agreement of simulated and observed values and thus improve the preliminary results presented here.

SECTION 6

ANALYSIS OF BMP EFFECTS ON WATER QUALITY

In order to simulate the effects of a proposed BMP scenario and to analyze the resulting effects of proposed selected BMPs, the effects of the desired BMPs on model parameters must be determined. These parameter adjustments and changes are then incorporated into the model and the simulation is performed again with the adjusted parameters; the results are compared to base conditions in order to assess the effects of the BMP scenario that was simulated. For our demonstration we have chosen the scenario of conservation tillage plus the use of contouring; the assumptions in our simulation of this scenario are listed in Table 6.1. These changes are based on studies performed as part of the Iowa Field Evaluation Program by Donigian, et al., (1983) to assess the effects of a variety of selected candidate BMP's on specific HSPF model parameter values.

Using the assumptions and associated changes in parameter values described in Table 6.1, the resulting comparison of this BMP scenario and the previously simulated base conditions (calibrated conditions) is shown in Table 6.1. Over the two and one-half year simulation period total runoff was reduced by 5% to 13% with an overall average of 8% reduction. Sediment loss reductions were considerably higher varying from 35% to 60% reduction with an overall average of 42% reduction over the simulation period. Although these sediment loss reductions are somewhat less than what might be expected, a significant portion of the total sediment loss is derived from the channel system itself, which would not be significantly affected by the BMPs.

Solution alachlor was reduced from 0% to 49% with an average of 32% reduction over the simulation period, whereas sediment alachlor was reduced from 0% to 69%, averaging 68% over the period. The 0% reduction in alachlor occurred in the year 1977 when essentially no significant runoff events occurred; this was the year of extreme drought in the Four Mile Creek area.

Nutrient simulation for both base conditions and the BMP scenario was performed only on a single year from Nov. 1977 to Oct. 1978. The reductions in Table 6.2 indicate a 23% reduction for nitrate, 12% reduction for chloride, and a 68% reduction for solution ammonia. The large ammonia reduction is partially due to reductions in sediment and sediment associated ammonia loadings from the land surface. The values listed for sediment associated ammonia and phosphate, and solution phosphate refer to edge-of-stream loadings since instream values were not simulated for these constituents. These reductions are also higher than the chloride and nitrate reductions since these three constituents

TABLE 6.1 SELECTED BMP SCENARIO FOR SIMULATION ON FOUR MILE CREEK, IA.

CONSERVATION TILLAGE PLUS CONTOURING

1. Chisel plowing replaces moldboard on corn residue followed by soybeans

2. Field cultivation replaces disking on soybean residue followed by corn

3. No change in infiltration parameter

4. Residues remain after harvest, with the following reductions by tillage and decay:

Moldboard	90%
Chisel	35%
Light disk	30%
Field cultivation	30%
Winter decay	
Soybeans	30%
Corn	10%

5. Reduction in sediment fines from tillage: 50 - 70%

6. UZSN increases due to contouring and less seedbed preparation

7. One summer cultivation replaces two cultivations under base conditions

8. Rainfall interception, surface roughness, and land cover increase to residues and less tillage

9. No change in chemical application amounts, but fall nitrogen fertilizer application moved to spring and summer. Incorporation distribution as follows:

	Surface	Upper
Moldboard	0%	100%
Chisel	50%	50%
Disking	20%	80%
NH3 Injection	0%	100%
Cultivation	40%	60%

10. No change in chemical (pesticide or nutrient) parameters, bulk density, or soil temperature.

TABLE 6.2 COMPARISON OF BASE CONDITIONS WITH BMP SCENARIO ON FOUR MILE CREEK, IA.

	BASE CONDITIONS	BMP SCENARIO	% DIFFERENCE
RUNOFF (mm)			
76	69.9	60.7	-13.2
77	48.8	43.7	-10.4
78	161.8	152.9	- 5.5
Total	280.5	257.3	- 8.3
SEDIMENT (tonne/ha)			
76	.437	.175	-60.0
77	.042	.022	-47.6
78	1.381	.888	-35.7
Total	1.860	1.085	-41.7
ALACHLOR (kg/ha)			
Solution:			
76	.00166	.00084	-49.4
77	.00009	.00009	0
78	.00212	.00168	-20.7
Total	.00387	.00261	-32.5
Sediment:			
76	.00012	.00003	-69.2
77	0	0	0
78	.00010	.00004	-60.0
Total	.00022	.00007	-68.2
NUTRIENTS (kg/ha): 11/77 - 10/78			
NO3	26.2	20.2	-22.9
Cl	34.0	30.1	-11.5
NH3-Sol	2.18	0.69	-68.3
* NH3-Sed	.00045	.00019	-57.8
* PO4-Sol	1.69	1.14	-32.5
* PO4-Sed	.00029	.00018	-37.9

* - Edge of Stream Loadings

are also affected by reductions in sediment erosion associated with the BMPs.

Table 6.3 shows the results of the simulation of the BMP scenario in terms of reductions in the fraction of time when acute and lethal conditions exist, following the lethality analysis methodology discussed previously. The values are presented in terms of both maximum daily values and average daily values. The specific choice of MATC and lethality data chosen for this analysis resulted in no change in the percent of time when acute conditions existed, primarily because the maximum simulated value was still sufficiently large to exceed the values that define the acute region under both conditions (base conditions and BMP scenario). However the reduction is shown in terms of the average values since the percent of time in the acute region was reduced by 50% under the BMP scenario. The fraction of time when lethal conditions exist, both acute and chronic, is represented by the values listed on the line entitled "Above The MATC Value". The reductions indicate an 8% reduction in the percent of time when lethal conditions occurred in the watershed. Obviously, reductions in the percent of time for lethal conditions will correspond to an increase in time for sub-lethal conditions.

Although the values listed here are specific to the conditions under which this BMP scenario was simulated, the overall methodology and analysis indicates how the procedures described can be used to evaluate the effects of BMP scenarios on the resulting risk of exposure of aquatic organisms to chemicals.

TABLE 6.3 LETHALITY ANALYSIS OF BMP SCENARIO FOR ALACHLOR IN FOUR MILE CREEK, IA. (Hypothetical organism)

	GLOBAL EXCEEDANCE (% of time)					
	BASE CONDITIONS		BMP SCENARIO		% CHANGE	
	MAX	AVER	MAX	AVER	MAX	AVER
ACUTE REGION	1.2	0.4	1.2	0.2	0.0	-50.
ABOVE MATC VALUE	3.2	2.5	2.9	2.3	-9.4	-8.0
SUBLETHAL REGION (below MATC)	96.8	97.5	97.1	97.7	+0.3	+0.2

MATC - Maximum Acceptable Toxicant Concentration (0.003 mg/l used above)
MAX - Daily maximum concentrations
AVER - Daily average concentrations

SECTION 7

STUDY CONCLUSIONS

The primary conclusions of this study are related to the results of HSPF simulations on field and watershed sites, the problem of field-to-stream sediment delivery, and the ability to evaluate and represent BMP effects with HSPF. On the field sites it is clear that tillage practices dominate the response of individual fields; consequently, in this study a true runoff verification was not possible due to lack of information on the effects of tillage on infiltration, surface detention, and other hydrologic processes.

In general, the sediment and pesticide simulations were mixed with good to poor results associated with the corresponding performance of the runoff and sediment simulation. Pesticide decay rates were highly variable; it is clear that a better predictive capability is needed in terms of representing and predicting pesticide decay in the field under various environmental conditions and factors.

With regard to nutrient simulation, the primary need at this time is better information on how to evaluate nutrient parameters, and more research into processes such as uptake of soil nutrients by legumes, the effects of crop residues on nutrient leaching and contributions to the soil, and other relevant processes.

For the watershed as a whole, the hydrology was well calibrated and verified. However, problems still exist in representation of the effects of tile drainage, the timing and volume of snowmelt, and the effects associated with frozen ground. The sediment and alachlor simulations for the entire watershed, both calibration and verification, were fair to good, especially when considering the error associated with the observed data. A key conclusion of this study was that the sediment, pesticide, and nutrient parameters calibrated on the field sites performed well at the watershed scale, primarily due to the hydrologic simulation providing a good representation of the transport mechanisms. It is clear that a good flow simulation is critical to overall watershed simulation.

Additionally, this work has shown that assumptions on agronomic practices, chemical applications, including timing, method etc., have a major impact on resulting chemical concentrations and loads measured at the watershed outlet.

The problem of field-to-stream sediment delivery still exists and has not been solved by the work performed here. It is clear that this problem is more significant for sediment and associated pollutants than for soluble pollutants. Our studies have shown that the delivery problem can be partially circumvented by a good representation of the flow and transport components at the watershed level. As noted above, sediment, pesticide, and nutrient parameters can be calibrated and determined for small field sites, and then used for the entire watershed, but the flow (transport) components must be representative of those occurring at the overall watershed level in order to obtain a reasonable watershed simulation.

Our experience with the model in this study has shown that HSPF provides a viable and flexible means of estimating the impacts of a wide range of candidate BMPs. Use of the model allows the user to closely analyze and demonstrate the impacts of specific assumptions incorporated within a BMP, e.g., chemical application, method and timing. However, true verification of the ability to simulate the effects of BMPs must await the availability of post BMP implementation data. Until such data has been collected, models such as HSPF can be used to estimate the effects of BMPs on stream water quality, and sensitivity analyses of various model parameters can assist the BMP evaluation and planning process.

SECTION 8

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